

EDITORS' NOTE

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Welcome to the inaugural issue of the *Lean Construction Journal* (LCJ). This journal will continue the revolution that began in 1992 with the thoughts and writings of Lauri Koskela. This journal is not inspired by a desire to create a cultish and guru-laden society. Rather, LCJ is committed to widening the appeal, readership, understanding and implementation of Lean Construction principles and concepts by providing a venue to share results of applied and basic research.

To our first time readers, the term '*Lean Construction*' may be alien or even an oxymoron. Before defining what it means, we must begin from the common ground of historic¹ *Construction Management*.

As many readers know, Construction Management as a field of applied science has escaped canonical definition. One typical definition is that of Clough and Sears (1994) "*The judicious allocation of resources to complete a project at budget, on time, and at desired quality*". This captures the essence of what inspires, drives and guides both practice and research in the Construction Management field.

The product-focus of historic Construction Management has created a slavish preoccupation with optimizing the transformation phase of an activity (the phase wherein shape, function, or form is changed). At the same time it overlooks:

- critical spatial and temporal coordination with other downstream and on-going production activities
- whether the project is extending the capabilities of the owner/end user.

The failure and inability of the conceptual models of historic Construction Management to deliver on the mantra of 'on-time, at budget, and at desired quality' or Quality, Cost and Delivery (QCD) is evident to practitioners and academics alike. Empirical data and project experience indicate that construction projects are low efficiency systems beset by endemic quality problems and rising litigation (Koskela 2000). Analysis of project schedule failures also indicated that "normally only about 50% of the tasks on weekly work plans are completed by the end of the plan week" and that most of the problems were possible to mitigate by contractors through an "active management of variability, starting with the structuring of the project (temporary production system) and continuing through its operation and improvement." (Ballard and Howell 2003).

Koskela's seminal 1992 report argued that the mismatch between the paradigms advanced by historic Construction Management and observed reality underscored the lack of robustness in the existing constructs of Construction Management and signaled the need for a theory of production in construction. As a result of an outward-oriented search into the production paradigms that dominated and competed in the

¹ We have deliberately chosen to use the word historic here following the usage in the Strategic Forum for Construction's Supply Chain Toolkit which you will find at <http://www.strategicforum.org.uk/>. The Maturity Assessment Grid uses historic as we intend it here. You will find a copy at http://www.strategicforum.org.uk/sfctoolkit2/help/maturity_model.html

manufacturing industries, namely, craft, mass and lean production paradigms, and using the ideal production system embodied in the Toyota Production System, Koskela conceived a more overarching production management paradigm for project-based production systems. Koskela presented the TFV theory of production wherein production was conceptualized in three complementary ways, namely, as a Transformation (T) of raw materials into standing structures, as a Flow (F) of the raw material and information through various production processes, and as Value generation and creation for owners through the elimination of value loss (realized outcome versus best possible) by ensuring customer needs and wants are captured and challenged.

This tripartite view of production has led to the birth of Lean Construction as a practice and discipline that subsumes the transformation-dominated historic construction management. A profound implication of the TFV concept of production is that it changes the definition of Construction Management to the *judicious allocation of resources to transform raw materials into standing structures while smoothing the flow of material and information – and maximizing value to the customer*. For example, the Last Planner System® developed by Ballard and Howell (1994), is a production planning and control system that requires all team members to collaborate actively in the process and create higher production unit performance and reliable work flow (hand-offs) between production units (see Ballard 2000 for more details).

Unlike historic product-focused Construction Management, Lean Construction considers construction as both a product and process. This dual focus means that Lean Construction is more than a production-based theory. And it is more than production and process too - it strives to concurrently improve the way we design and build structures for end-users and builders.

Koskela and Howell (2002) presented a comprehensive review of the shortcomings of existing *project management* (PM) theory - specifically as related to the planning, execution, and control paradigms in project-based production systems. They suggested that planning-as-organizing, the action/language perspective, and the scientific experimentation model were critically needed elements to make Project Management theory more robust and contemporaneous.

Bertelsen (2003a and 2003b), a seasoned construction manager with over 40 years experience, suggested that construction should be modeled using chaos and complex systems theory and that construction could and should be understood in three complimentary ways

- as a project-based production process,
- as an industry that provides autonomous agents, and
- as a social system.

All these conceptualizations, the TFV theory, the new PM theory, and the construction complexity view, provide a solid intellectual foundation for Lean Construction in both research and practice.

While Lean Construction is identical to Lean Production in spirit, it was conceived and is practiced differently. Lean Construction is more than a mere imposition of the Toyota Production System onto construction. It is more than just the *simple common sense* that some have suggested (though we are pleased to hear it so labeled); it is a

paradigm challenging the incumbent one presented by historic Construction Management.

As with most paradigms (Kuhn 1962) it is taking a while for Lean construction to replace the dominant historic paradigms in Construction Management and Project Management. In UK where central government has been actively involved for the last 10 years in trying to change the dominant paradigm recent research in the public sector shows that only around 2% of local government construction procurement is done collaboratively and without tendering.

Given the challenges facing the construction industry we can only conclude that common sense is rather uncommon. We want this Journal to become the primary forum for the discussion of uncommon sense in relation to construction management and project management.

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Generic Implementation of Lean Concepts in Simulation Models

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Lean production theory, as a production management tool, describes a system that delivers a finished product free from defects, to a customer in zero time, and with nothing left in inventory. Recently, the concepts of lean production have been introduced to construction yet have generally been rejected. Lean construction concepts were recently tested in a simulation environment and were found to be effective. To facilitate the implementation of the concepts of lean production in construction simulation, and subsequently within an actual construction project, a generic approach has been created and is presented in this paper. A special purpose simulation (SPS) template was developed for surface works operations in road construction as an example application. The template provides a means of testing the concepts of lean production on road construction simulation models to quantify their impact on road construction processes. This general approach for implementing lean production theory in construction simulation modeling also proved capable of directing the process of optimizing simulation models.

Keywords: lean production theory; optimization; construction simulation; special purpose simulation.

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1. Introduction

As a production management tool, lean production theory describes a system that delivers a finished product free from defects to a customer, in zero time, and with nothing left in inventory. Moreover, it can be summarized into three main points: 1) eliminate or reduce all activities that do not add value to the final product, 2) pull material through the process (instant delivery of required materials), and 3) reduce variability by controlling uncertainties within the process.

Lean production was initially developed for the manufacturing industry and has been widely accepted in that field. This concept has only been recently introduced to the construction industry and has not yet been very successful, due largely to the belief that construction has unique and complex projects in highly uncertain environments that are under great time and schedule pressure (Howell 1999), which makes it somehow different from the manufacturing industry.

In addition, the construction industry has historically been very slow to change in many respects, which makes implementing the concepts of lean production theory very difficult. Industry practitioners are wary of implementing new techniques on large, complex projects. Implementing a fundamentally different management system on a multimillion-dollar project could be viewed as risky. For this reason, computer simulation provides an excellent environment to implement the principles of lean production, study their effects, and gain a better understanding of how these principles can be applied to real construction projects. Pioneering work in this area has already been conducted where lean concepts were tested in a structural steel erection model (Al-Sudairi et al. 1999). The results from this implementation were very positive, though the model and approach were process-specific to steel erection.

Thus, the first objective of this paper is to develop a generic approach that will facilitate the implementation of the concepts of lean production theory into construction simulation models. Then, a special purpose simulation template is presented to allow industry practitioners to create computer models of surface works road construction projects that will facilitate both scenario analysis and lean production principles. Finally, a case study of the Anthony Henday Drive Extension project is presented to validate the methodology.

2. Background

2.1. Construction simulation

Computer simulation is defined by Pristker (1986) as the process of designing a mathematical-logical model of a real world system and experimenting with the model on a computer. Simulation has proved to be a valuable analytical tool in many fields. Particularly, it is powerful when studying resource-driven processes since it provides a fast and economical way to experiment with different alternatives and approaches. Furthermore, key factors in the process can be identified through an in-depth understanding of the interactions of resources and processes.

Construction operations include many processes. The flow between processes and the resource utilization at every step thus determines the performance of the whole project. To understand the interaction of construction processes and the impact of resource supply, the construction project planner can experiment with different

combinations of construction processes and varying levels of resource supply in a simulation environment to seek the best performance for their construction operation.

Halpin (1973) first introduced simulation to construction with the CYCLONE modeling method. Since then, various construction simulation systems have been created based on CYCLONE, which include INSIGHT (Paulson 1978), RESQUE (Chang 1987), UM-CYCLONE (Ioannou 1989), COOPS (Liu and Ioannou 1992), DISCO (Huang et al. 1994), CIPROS (Tommelein and Odeh 1994), and STROBOSCOPE (Martinez and Ioannou 1994).

According to Hajjar and AbouRizk (1999), simulation modeling is made most effective for use in the construction industry through the specialization and customization of modeling, analysis, and reporting components within the simulation system. This philosophy led to the development of Symphony, a comprehensive platform for both general and SPS application and development.

2.2. Lean production theory

Taiichi Ohno, an engineer working for Toyota, developed lean production theory as a method of eliminating waste. Ohno shifted the attention of researchers away from the effect of worker productivity on craft production alone towards a consideration of the production system as a whole. Ohno followed the work of Henry Ford in continuing the development of flow-based production management (Howell 1999).

The underlying goal of lean production theory is the avoidance, elimination, or reduction of waste. Howell (1999) defines waste by the performance criteria for a particular production system; failure to meet the unique requirements of a client is considered waste. Howell goes further in outlining this criterion by defining waste as time, space, or material used in the performance of an activity that does not directly contribute value to the finished product. Using these broad definitions for waste, lean production theory attempts to move a production system towards perfection, or zero waste.

Koskela (1992) describes the conventional production philosophy as a "Conversion Model", which is comprised of the following items:

- A production process is a conversion of an input to an output.
- The conversion process can be divided into sub-processes, which are also conversion processes.
- Minimizing the cost of each sub-process can minimize the cost of the total process.
- The value of the output of a process is associated with the costs (or value) of inputs to that process.

Lean production theory interprets the production system as a series of conversions and flows. Conversion activities are those activities that add value to the final product. Flow activities are those activities that transfer the product to and from conversion activities. A primary goal of lean production theory is to reduce or eliminate the share of flow activities in a project while increasing the efficiency of conversion activities. The following list outlines key principles of lean production theory (Koskela 1992):

- Reduce the share of non value-adding activities.
- Increase output value through a systematic consideration of customer requirements.
- Reduce variability.
- Reduce cycle times.

- Simplify by minimizing the number of steps, parts, or linkages.
- Increase output flexibility.
- Increase process transparency.
- Focus control on the overall process.
- Build continuous improvement into the process.
- Balance flow improvement with conversion improvement.
- Benchmark.

Though lean production theory was developed for manufacturing, the similarities between craft manufacturing and the construction process make lean production theory very applicable to construction.

2.3. Simulation modeling and lean construction

Tommelein (1998) indicated that the reason for the development of lean construction principles is that current industry project management tools are unable to describe adequately the construction process at a level on which lean production can be studied. Tommelein (1998) used a game called "The Parade Game" to demonstrate how linked operations affect one another in construction processes. Her developments form the underpinning of the work we describe in this paper.

Al-Sudairi et al. (1999) reported positive results when the following five lean principles were implemented in generic steel erection computer simulation model: precisely specify value by specific product, identify the value stream for each product, make value flow without interruptions, let the customer pull value from the producer, and pursue perfection. An overall improvement was noted; however, the model became volatile and sensitive to variances in the process. It was determined that construction buffers are critical components to the implementation of lean principles. Buffers allow faster processes to continue with a minimum number of stoppages.

This research demonstrated how to incorporate the concepts of lean production into computer simulation models. In addition, the work that has been completed focuses on the application of lean concepts on unique, stand-alone models; a framework for the generic implementation of lean concepts in any computer model has not yet been developed.

3. Integrated SPS Template

3.1. Surface works operation in road construction

Surface works operations of road construction can be grouped into three main categories: subgrade operations, aggregate operations, and asphalt operations.

3.1.1. Subgrade operations

As the name suggests, subgrade operations involve the preparation of subgrade to a specified degree in order to ensure an appropriate foundation for the aggregate and asphalt structures of a road. Depending on the condition of the original ground, there are several different processes that can occur. These processes can involve (but are not limited to) grading the clay to ensure proper elevation, drying or stabilizing the soil and

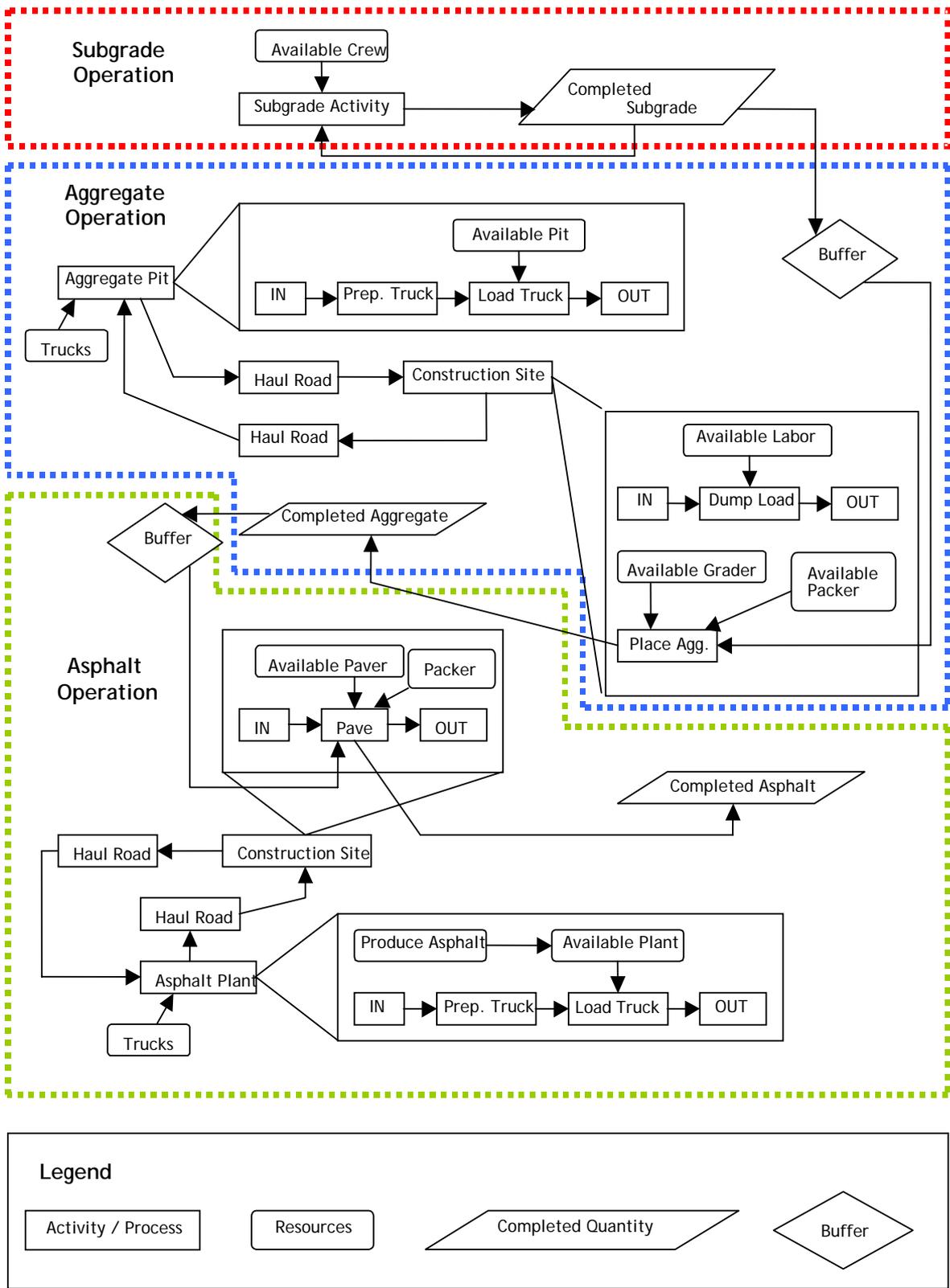


Fig. 1. Surface works road construction operations process flow chart

re-compacting it to a specified density, or in extreme cases, excavating and replacing unsuitable material from the roadway.

3.1.2. Aggregate operations

Aggregate operations involve the supply and placement of aggregate to the construction site. It is desirable for aggregate placement to follow closely behind subgrade preparation in order to “protect” it from poor weather. There are three main sub-processes that combine to govern the overall production rate of the aggregate operation: the aggregate pit, haul cycle, and on-site placement. The resources required for this operation include a loader at the aggregate pit, aggregate haul trucks, site labour, grader(s) to place the material, and packers to ensure that density requirements are met.

3.1.3. Asphalt Operations

Asphalt operations involve the production, supply, and placement of asphalt to the construction site. Three main sub-processes govern the overall production rate: the asphalt plant, haul roads, and on-site placement. The resources required for this operation include the asphalt plant, asphalt haul trucks, the asphalt paver(s), and packer(s).

3.2. Development of the surface works road construction template

The Surface Works Road Construction (SWRC) template was developed using the flow chart depicted in Figure 1. It shows the main processes of surface works road construction and how they interact. The flow chart was created by simplifying the overall process of road surface construction in which the subgrade, aggregate, and asphalt operations work concurrently.

The simulation begins with the subgrade operation. Once the Subgrade-Aggregate buffer has been reached, the Aggregate operation is allowed to begin. If at any time the aggregate quantity placed overcomes the Subgrade-Aggregate buffer, the Aggregate operation is halted until the buffer is restored. Once the Aggregate-Asphalt buffer has been reached, the Asphalt operation is allowed to begin. The same rules apply to this buffer as to the Subgrade-Aggregate buffer. The model proceeds in this cyclic fashion until the road construction is completed.

As shown in Figure 2, a number of elements are created for SWRC template, including: Construction Site, Subgrade Operation Element, Aggregate Placement Element, Asphalt Placement Element, Asphalt Plant Element, Aggregate Pit Element, Haul Road Element, Aggregate/Asphalt Truck Elements, and Create Truck (Asphalt/Aggregate). The main interface of the SWRC template displays a simplified relationship between the asphalt plant, gravel pit, and road construction site. More precisely, the Construction Site element is composed of a subgrade operation, an aggregate operation, and an asphalt operation as demonstrated in Figure 3. Each of these elements represents the top node in a hierarchy that represents interactions between various resources and activities at its lowest level of detail, as shown in Figure 4. Further information on the SWRC template is available in Farrar (2002).

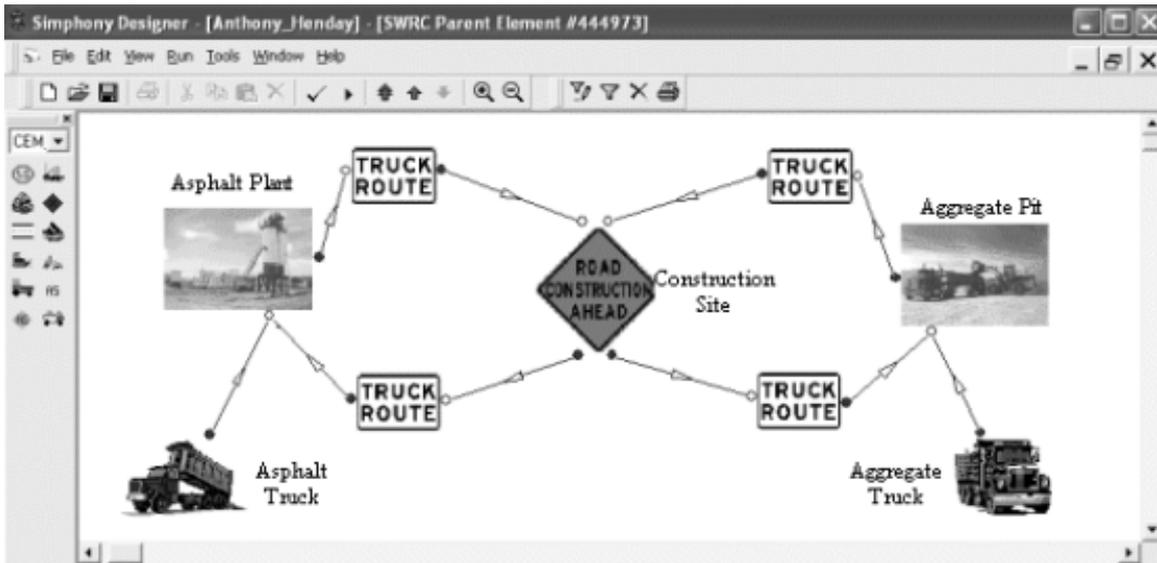


Fig. 2. SWRC example model

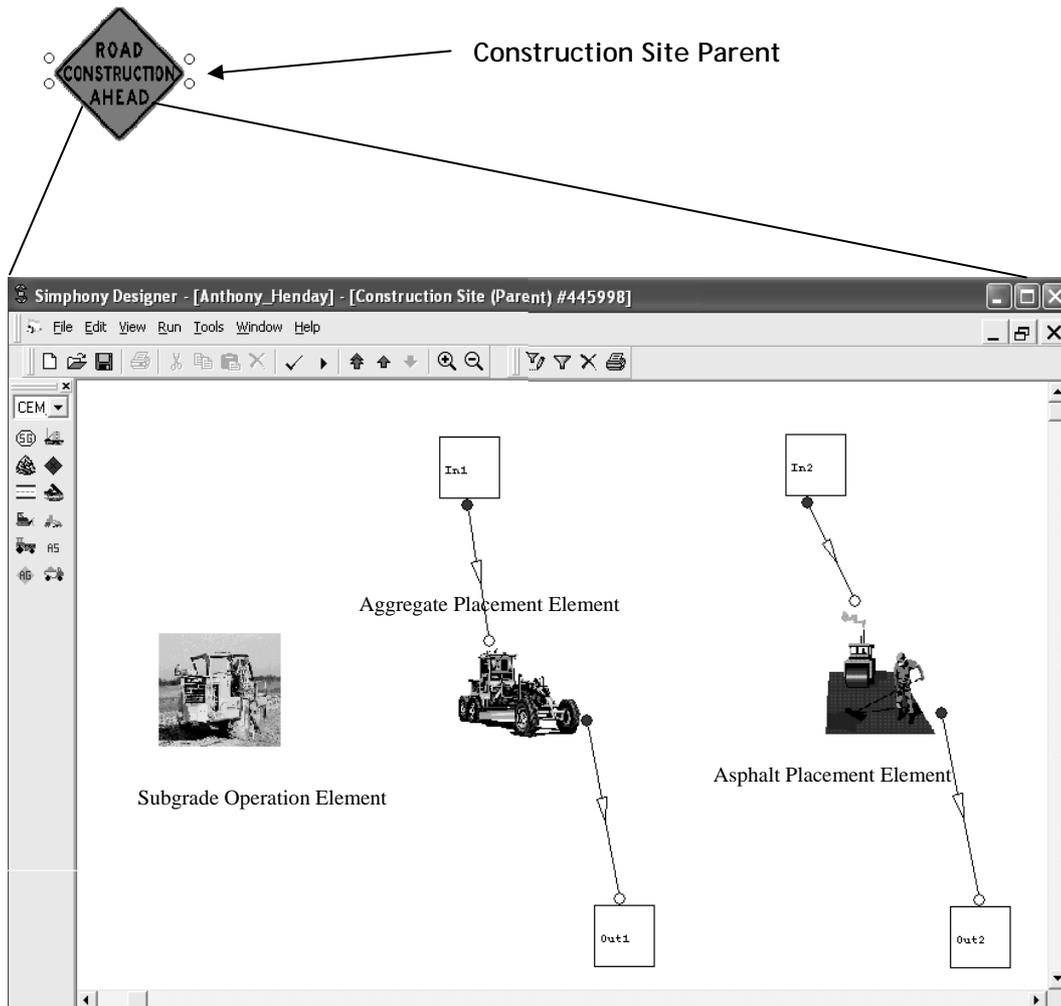


Fig. 3. Construction site child elements

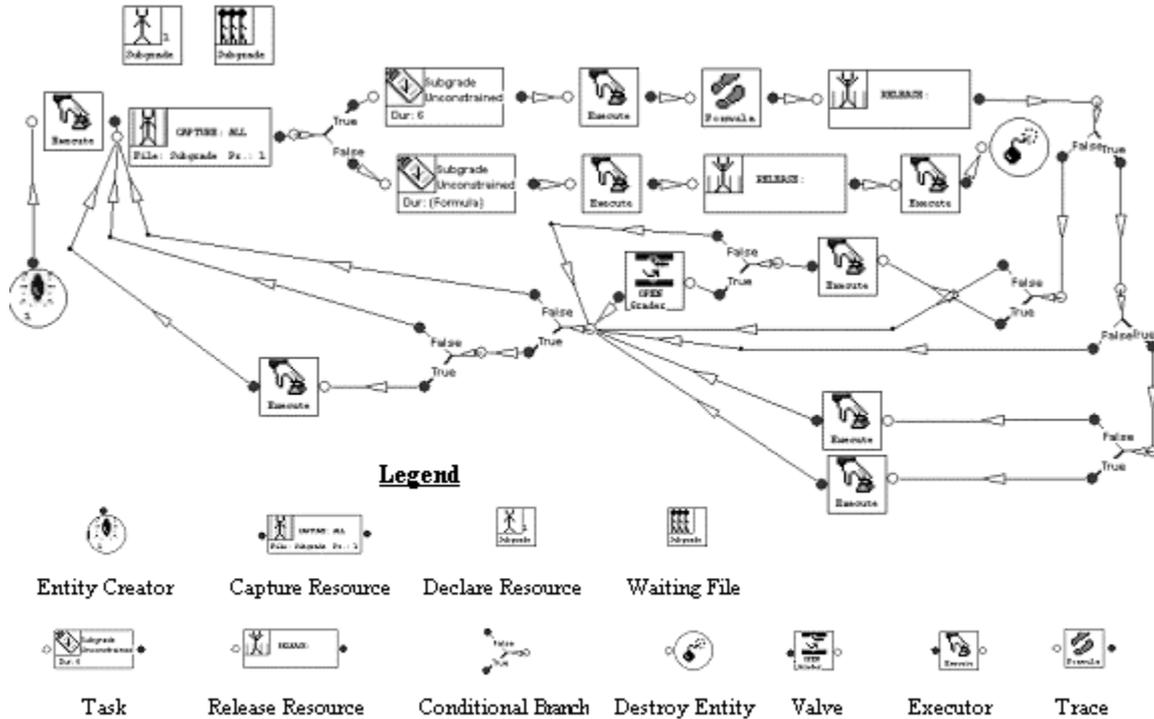


Fig. 4. Detail of subgrade operation element

Once a simulation model has been run, the SWRC template produces several statistical outputs, including:

- (1) Operational Production Rates. For each operation (Subgrade, Aggregate, or Asphalt) statistical data for hourly production is collected during the course of the simulation. This information is displayed both numerically and graphically.
- (2) Resource Utilization. For each resource in the model statistical data is collected for both utilization and queue-waiting times. This information is displayed both numerically and graphically.
- (3) Cycle Times. The material haul cycle (aggregate and asphalt) plays a significant role in the overall model. Truck cycle time data is collected during the simulation run and is displayed both numerically and graphically.
- (4) Miscellaneous. Other outputs produced by the template include operational durations, overall project duration, measured throughput (overall), and cumulative quantity tracking.

Using these simulation outputs, the user can perform a variety of analytical functions including model sensitivity analysis, scenario analysis, and lean construction theory analysis. Sensitivity analysis allows users to change various input parameters and measure the impact of this change on the model. This enables practitioners to determine which activities are critical and require the most attention. Scenario analysis allows a user to model several different situations, and to compare the output. For example, one could use the model to determine the number of haul trucks to use by modeling several different scenarios and choosing the best result. The model can also be analyzed using lean construction theory.

3.3. Application of lean concepts

In this work, lean principles are applied to a simulation model that has been built using a special purpose simulation template instead of a simulation model that stands alone. This difference is very significant because the lean principles that are implemented in this section are done so using a generic set of guidelines that can be applied to any model created using the SWRC template or otherwise.

The principles of lean production as outlined by Koskela (1992) can be separated into three central themes:

- (1) Identify and deliver value to the customer: eliminate waste
- (2) Increase output value: pull inventory
- (3) Create reliable flow: reduce variability

3.3.1. Eliminating waste

A construction process is comprised of those activities that add value to the finished project, and those that do not. By definition, a value-adding activity is one that converts the materials to products which are able to meet customer requirements. A non value-adding activity is one that takes time, resources, or space but does not add value (Koskela 1992). Whatever the cause, according to lean principles, if non value-adding activities can be reduced or eliminated, waste in the process can be decreased. Eliminating waste is a fundamental concept of lean production theory.

3.3.2. Pulling inventory

The term “pulling inventory” means that material is delivered to the process as soon as it is needed. In most construction projects, material is pushed through each process, forcing the project to slow down or halt altogether until this material has been delivered. As a result, it is the supply of material that pushes or drives the construction process (Tommelein 1998). Pulling material as soon as resources are required is considered instant delivery.

3.3.3. Reducing Variability

Variability will exist in any process where operations are dependent on the delivery of material or products or where linked operations have different production rates. One solution that has been developed to respond to variation in construction projects is the use of buffers. According to Howell et al. (1994), buffers can serve at least three functions in relation to shielding work by providing a workable backlog:

- To compensate for differing average rates of supply and use between the two activities,
- To compensate for uncertainty in the actual rates of supply and use, or
- To allow differing work sequences by the supplier and user.

Buffers are important tools because they allow two activities, whose productions are closely linked, to proceed independently of one another (Howell et al. 1994). The SWRC template has two buffers which are used between the subgrade and aggregate operations, and between the aggregate and asphalt operations. They can be used to compensate for the varying production rates of these operations.

3.3.4. Guidelines for the implementation of lean principles in simulation models

A number of experiments utilizing the developed SWRC template were performed in an attempt to develop guidelines for the implementation of the lean principles described in Section 3.3.1 into simulation models. These experiments led to the development of the following guidelines, which proved to be the most effective for implementation:

- (1) Select all non value-adding activities in the simulation model (candidates for improvement). Use the definition provided by Koskela (1992) in the previous section to focus on those activities that do not add value to the operation.
- (2) Set the task durations of the improvement candidates to zero (one at a time). Although, in many cases, eliminating these activities is not possible or practical, doing so will allow one to determine their significance on the model output.
- (3) Produce simulation results (run the simulation).
- (4) Sort the candidates in order of their significance to the simulation model. This will enable the improvement process to focus on those activities that have the greatest impact on model outputs.
- (5) Look for practical activity reduction solutions for the candidates, starting with the activity that has the greatest potential for improvement.
- (6) Edit the simulation model to reflect zero-time delivery of required materials. Although this may not be possible or practical, it will allow one to determine the effect that the material delivery process has on model outputs.
- (7) Produce simulation results (run the simulation).
- (8) Look for practical solutions to improve the material delivery processes (if required). If the material delivery process has a significant impact on model outputs, efforts should be made to make practical improvements.
- (9) Look for practical solutions to improve production activities. Only after the lean concepts (value-adding activities, and pull-driven flow) have been introduced to the model should the improvement be focused on production activities.
- (10) Introduce buffers to compensate for increased model variability and for differing production rates of linked operations. The lean production improvement process has generally been shown to introduce significant variability into processes. Buffers should be introduced as a final step to compensate for this effect.

4. Case Study: Anthony Henday Drive Extension

To implement the concepts of lean production using the proposed guideline, a base model is created using the SWRC template that serves as a benchmark for the experiment. How a specific lean principle influences the SWRC model is determined by comparing the output of a lean concept-improved model with the output of a base model. A base model was created using the SWRC template in accordance with the actual data obtained from the Anthony Henday Drive project. This project is a part of the City of Edmonton's and the Province of Alberta's transportation and utility plan and plays an important role in the overall provincial North-South Trade Corridor. The model used in this experiment is of a typical road section, 14-m wide and 1.5-km long. The road structure is made up of 300-mm of aggregate and 100-mm of asphalt on prepared subgrade. The long-distance road and repetitive nature of its construction process made the Anthony Henday Drive Extension an excellent choice for simulation using a model created from the SPS template.

In addition, three base models were used in order to determine how different haul distances affect model outputs when lean principles are introduced; those distances

include 5-kms (short), 30-kms (medium), and 100-kms (long), and are used for both the aggregate and asphalt operations.

4.1. Validation of SWRC Model

To validate a computer model, two types of data are required. First, input data for the model is required so that the same input parameters are used as were used in the actual project. Second, validation data such as production rates and resource utilization rates were required to compare with the model output. The output produced by a simulation model must yield results relatively similar to the actual project in order for the model to be validated. Both types of data came from a variety of sources, including project time sheets, field quantity reports, trucking haul tickets, time studies, and discussions with industry practitioners.

4.1.1. Data for Model Input

Table 1 describes the model input data that was required to accurately model the Anthony Henday Drive Extension Project. Several of the model inputs are in the form of statistical distributions. Uniform (UNI), Triangular (TRI), and Beta (BETA) distributions were used. Uniform and Triangular distributions are often used because their meaning is easily understood and has the smallest data requirement. The Uniform distribution is the simplest continuous distribution in probability. It has a constant probability density on an interval (a , b) and zero probability density elsewhere. The distribution is specified by two parameters: the end points a and b . Triangular distribution is typically used to describe a subjective analysis of a population based on the knowledge of the minimum and maximum and an average value in between. It is a very useful distribution for modeling processes where the range of variables is known, but data is scarce. A Beta distribution is more complicated. This type of distribution is good for representing data that has been previously collected, because it is considered a flexible distribution. The input values that were determined through detailed analysis and data collection were fitted with Beta distributions.

Table 1. Anthony Henday Drive validation model input parameters

Element	Input Description	Value	Source
Construction Site	Total Road Area	123,000 m ²	Field Quantity Report
Subgrade Operation	Production Rate	UNI(550,700) m ² /hr	Industry Practitioners
Aggregate Operation	Grader Production Rate	TRI(700,720,780) tonne /hr	Industry Practitioners
	Truck Dumping Time	UNI(2,5) min.	Assumption
	Aggregate Pull	1.74 tonne/m ²	Physical Property of Aggregate
	Subgrade Buffer	12,500 m ²	Field Quantity Report & Time Sheets
Asphalt Operation	Paver Placement Rate	BETA (1.07,3.58,449.42,1804.80) tonne /hr	Paver Time Study
	Truck Positioning Time	TRI (0.50,0.90,2.00) min.	Paver Time Study

	Asphalt Pull	0.234 tonne/m ²	Physical Property of Asphalt
	Number of Pavers	2	Industry Practitioners
	Aggregate Buffer	31,000 m ²	Field Quantity Report & Time Sheets
Aggregate Pit	Truck Loading Rate	UNI (500.00,600.00) tonne/hr	Industry Practitioners
	Truck Prep. Time	UNI (2,3) min.	Industry Practitioners
Asphalt Plant	Production Rate	TRI(300.00,325.00,400.00) tonne/hr	Industry Practitioners
	Truck Load Time	UNI(2.00,3.00) min.	Industry Practitioners
	Storage Capacity	300 tonne	Physical Property of Asphalt Plant
	Truck Prep. Time	UNI (2,3) min.	Industry Practitioners
Aggregate Haul Road	Length	70 km	Industry Practitioners
	Ave. Speed Limit	90 km/hr	Assumption
	Expected Delay	UNI (5,10) min.	Assumption
Asphalt Haul Road	Length	24 km	Industry Practitioners
	Ave. Speed Limit	90 km/hr	Assumption
	Expected Delay	UNI(5,10) min.	Assumption
Aggregate Trucks	Number	23	Industry Practitioners
	Loaded Speed	90 km/hr	Assumption
	Empty Speed	100 km/hr	Assumption
	Capacity	BETA (2.65,3.84,20.85,42.61) tonne	Truck Haul Tickets
Asphalt Trucks	Number	18	Industry Practitioners
	Loaded Speed	90 km/hr	Assumption
	Empty Speed	100 km/hr	Assumption
	Capacity	BETA (5.45,1.32,11.87,15.77) tonne	Truck Haul Tickets

4.2. Simulation model vs. actual project comparison

Table 2 outlines the model outputs and actual project values that were used for comparison. Production rates were used for this comparison because they are often the most critical numbers for both estimating and job-costing purposes.

Table 2. Anthony Henday Drive simulation model vs. actual project output

Description	Model Output	Actual Output	Difference (%)
Overall Subgrade Production Rate (m ² /hr)	624.7	620.7	0.64
Overall Aggregate Production Rate (tonne/hr)	337.9	355.1	4.8
Overall Asphalt Production Rate (tonne/hr)	290.8	298.5	2.6
Paver Utilization Rate (%)	31.4	33.3	5.7
Paver Truck Change (%)	16.4	17.0	3.5
Project Duration (hrs)	677.7	733.5	7.6

Through a detailed analysis, the SWRC model was found to perform well insofar as the output of the simulation model and the output of the actual project were extremely close to each other. The reliability of the SWRC template-based model enables both researchers and industry practitioners to perform various lean production theory analyses upon a model that has been proven to resemble closely the actual construction process.

4.3. Implementing the “lean” guidelines

Each of the guidelines described earlier was implemented. Their corresponding impacts were quantitatively identified based upon the base model.

4.3.1. Identify and deliver value to the customer

A value-adding activity is one that converts the materials to products in order to meet customer needs. Accordingly, all activities of road surface construction were distinguished as either value-adding or non value-adding. Subgrade preparation, aggregate placement, and asphalt placement are value-adding activities because they are the essential steps that convert raw road construction materials into a final product, i.e. road surface. It is assumed that the asphalt plant and aggregate pit are away from the road construction site. Therefore, transportation, as an aspect of conversion encompassed within road surface construction, is defined as value-adding activity. On the other hand, truck preparation and truck position are defined as non value-adding activities because they do not add value to final production and could potentially be reduced or eliminated.

In order to determine the impact that non value-adding activities (improvement candidates) have on the simulation model, they were removed and the simulation was run. For the purpose of this experiment all of the improvement candidates' durations were set to zero simultaneously in order to determine the model's “potential for improvement” in this area. The model outputs from this procedure are compared to the base model in Table 4.

Table 3. Value and non value-adding activities

Process	Activity	Value-Adding?
Subgrade Operations	Subgrade Preparation	YES
Aggregate Pit	Truck Preparation Time	NO
	Aggregate Transportation	YES
Aggregate Operations	Truck Dumping	NO
	Aggregate Placement	YES
Asphalt Plant	Truck Preparation	NO
	Asphalt Production	YES
	Loading of Trucks	NO
	Asphalt Transportation	YES
Asphalt Operations	Position Truck	NO
	Asphalt Placement	YES

In order to determine the impact that non value-adding activities (improvement candidates) have on the simulation model, they were removed and the simulation was run. For the purpose of this experiment all of the improvement candidates' durations were set to zero simultaneously in order to determine the model's "potential for improvement" in this area. The model outputs from this procedure are compared to the base model in Table 4.

Table 4 shows an overall improvement of the model's performance. When the non value-adding activities are removed from the process, however, the improvements change as the haul distances vary. Generally speaking, the percent improvement, as compared to the base model, decreased as the haul distances increased. The reason for this is that as the haul distances increase the material delivery delay time also increases. In other words, as the share of non value-adding activities is reduced, their impact likewise becomes relatively small. Although the statistics collected show great improvement, velocity diagrams of each haul distance case yield interesting results. Figures 5, 6, and 7 display the velocity diagrams for each of the haul distances.

As mentioned, the long haul case did not change as significantly as the medium and short haul cases. In those cases (more so in the short case), significant variability was introduced as non value-adding activities were eliminated. The term, "variability", in this respect, is meant to indicate non-continuous production, and not necessarily erratic production values. The aggregate operation, for example, was stopped due to operational interference with the subgrade process a total of 5 times (in both cases) as opposed to the zero times this occurred in the base model (this will be discussed further in Step 10). The data collected from this experiment indicates that in surface works operations, non value-adding activities have the greatest effect on the process when the haul distances are short.

Table 4. Value-adding activities model output vs. base model output

Description	% Change from Base Model		
	Short Haul	Med. Haul	Long Haul
Project Duration	0.00%	-8.69%	-5.29%
Project Throughput	1.07%	9.70%	5.66%
Aggregate Operations			
Total Working Time	-0.45%	-6.92%	-4.88%
Total Time	0.00%	-6.92%	-4.88%
Avg. Production Rate	0.36%	7.35%	5.09%
Avg. Grader Utilization	1.82%	6.68%	3.04%
Asphalt Operations			
Total Working Time	-27.06%	-14.49%	-8.09%
Total Time	-1.35%	-9.73%	-5.80%
Avg. Production Rate	35.00%	15.30%	7.18%
Avg. Paver Utilization	46.90%	17.12%	19.80%

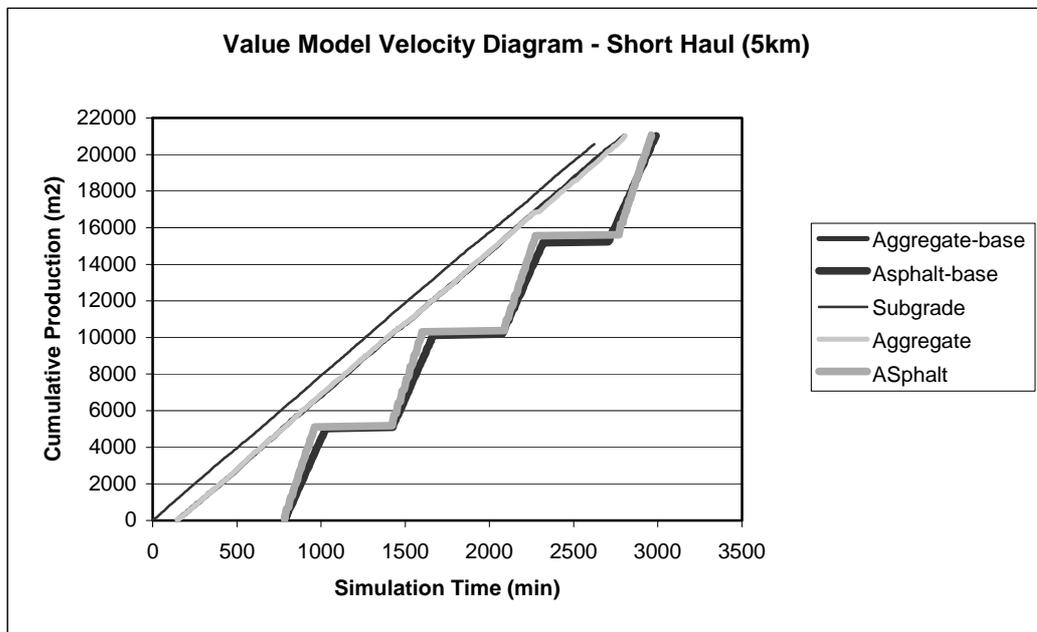


Fig. 5. Value-adding model vs. base model - velocity diagram (short haul, 5-kms)

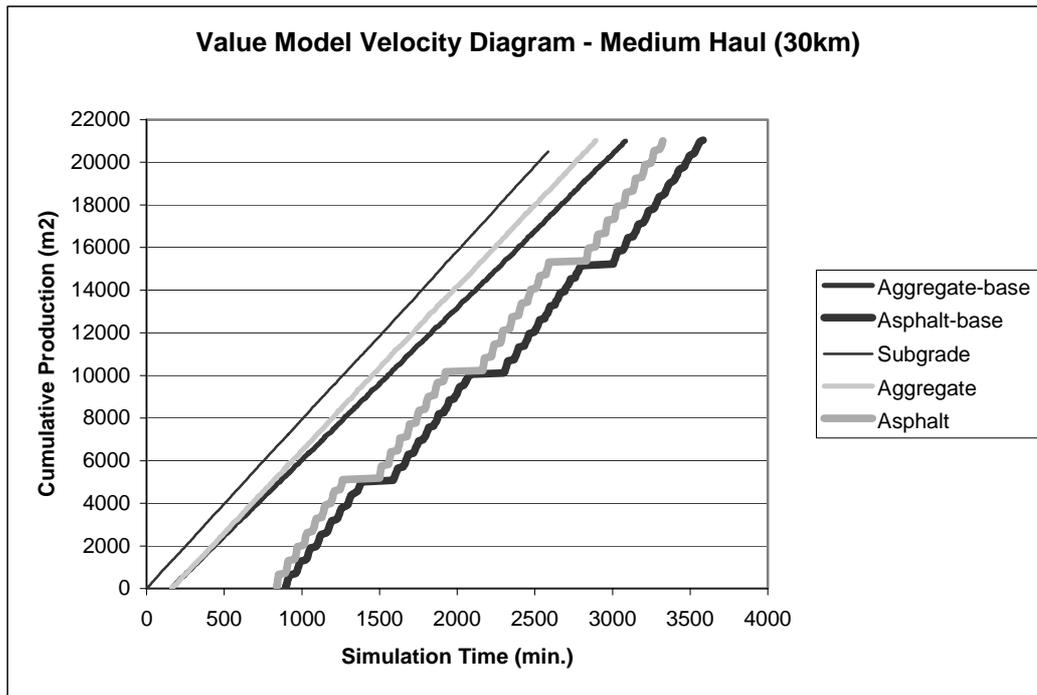


Fig. 6. Value-adding model vs. base model - velocity diagram (med. haul, 30-kms)

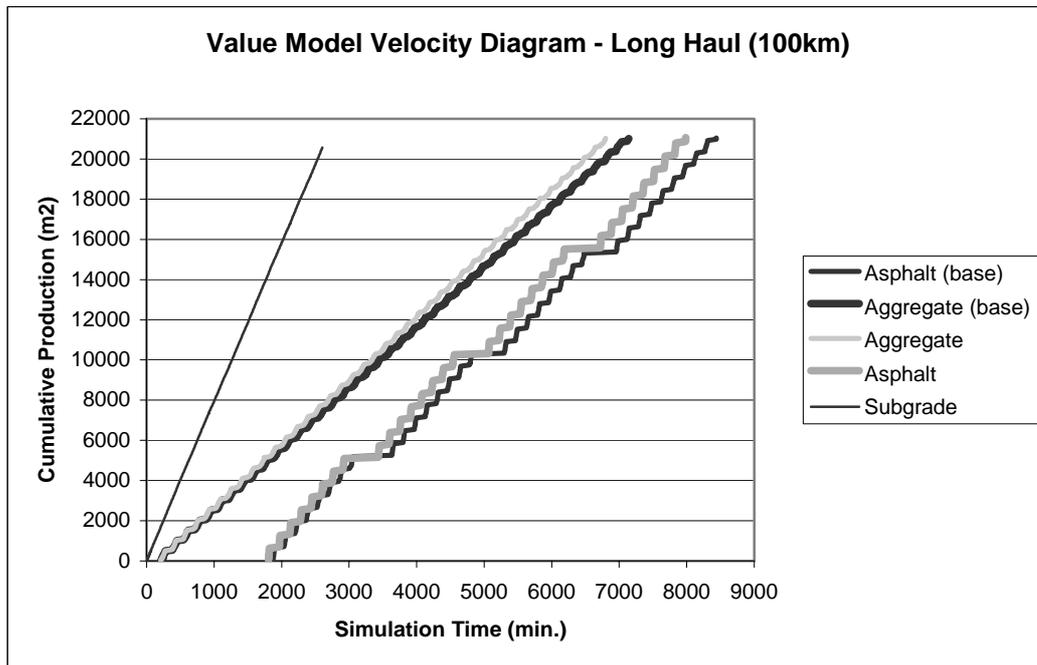


Fig. 7. Value-adding model vs. base model - velocity diagram (long haul, 100-kms)

It is clear that non value-adding activities combine to have a significant effect on model outputs; however, it is also desirable to know which non value-adding activities have the most significant effect. This knowledge will enable industry practitioners to have a starting point for determining the activities that should be examined more closely when attempting to improve the system. Using the same experimental procedure as in Step

Three, each non value-adding activity was eliminated, one at a time, so that their individual significance could be ranked. The results of this process are summarized in Table 5.

Table 5. Ranked non value-adding activities

Non-Value-Adding Activity Eliminated	Production Rate (tonne/hr)	% Change	Rank
Short Haul (5-kms)			
Aggregate Operations			
Truck Dumping at Site	338.1	1.05%	2
Truck Prep. Time at Pit	338.5	1.17%	1
Asphalt Operations			
Truck Prep. at Plant	311.0	7.24%	2
Truck Loading at Plant	336.7	16.10%	1
Truck Position at Site	307.7	6.10%	3
Medium Haul (30-kms)			
Aggregate Operations			
Truck Dumping at Site	314.3	9.47%	2
Truck Prep. Time at Pit	317.7	10.66%	1
Asphalt Operations			
Truck Prep. at Plant	149.4	4.84%	2
Truck Loading at Plant	150.0	5.26%	1
Truck Position at Site	148.4	4.14%	3
Long Haul (100-kms)			
Aggregate Operations			
Truck Dumping at Site	130.0	1.80%	1
Truck Prep. Time at Pit	131.9	3.29%	2
Asphalt Operations			
Truck Prep. At Plant	61.1	4.44%	2
Truck Loading at Plant	61.2	4.62%	1
Truck Position at Site	60.0	2.56%	3

The data presented in Table 5 suggests several interesting results. For the aggregate operation, the most significant non value-adding activity was "Truck Loading at the Pit" for each of the three haul distances. For the short haul distance, however, the improvement caused by this activity's removal was much more significant than for the other hauls. This is because when the loading activity was eliminated, the short haul resulted in an excess of trucks (enough trucks were hauling to ensure that the Grader was utilized close to 100% of the time). "Truck Dumping at the Site" and "Truck Preparation at the Pit" were shown to have a greater effect on production than the

loading of aggregate at the pit. For the asphalt operation, the candidates much more equally shared the improvements. Nonetheless, eliminating truck loading at the plant consistently improved the production rate for all of the haul distances.

It should be noted that the impact of reducing non value-adding activities on a simulation model depends greatly on the complexity of that model. Lee et al. (1999) point out that when activities are simplified for analytical purposes waste in those activities may go unnoticed. The relative simplicity of a computer simulation model compared to actual construction processes, results in certain value-adding activities having, in actuality, non value-adding tasks embedded within them. For example, in an actual construction process the asphalt placement activity might involve inspection, materials testing, survey checks, and/or equipment maintenance, all of which are considered non value-adding. Analyzing activities to this degree using computer simulation becomes impractical because of the highly complex and detailed simulation models that would be required. Such complex models would be less flexible in terms of their applicability and are more difficult to use.

4.3.2. Increase Output Value

To determine the impact that the material delivery process will have on the model outputs, the model is changed to reflect a zero-time delivery for both aggregate and asphalt operations. This change can be accomplished by increasing the number of resources transporting the material to the point where the resources that require them are utilized 100% of the time. In the example model this translates into the haul trucks waiting for the aggregate and asphalt operations rather than the other way around. Table 6 illustrates the model output that results from making this change.

Table 6. Pulling material model output vs. base model

Description	% Change from Base Model		
	Short Haul	Med. Haul	Long Haul
Project Duration	-15.20%	-32.07%	-68.15%
Project Throughput	17.76%	47.37%	213.69%
Aggregate Operations			
Total Working Time	-8.30%	-20.71%	-64.07%
Total Time	-8.30%	-20.71%	-64.07%
Ave. Production Rate	9.03%	25.95%	177.76%
Ave. Grader Utilization	18.73%	34.09%	169.91%
Asphalt Operations			
Total Working Time	-59.41%	-79.71%	-91.68%
Total Time	-12.94%	-32.71%	-69.76%
Avg. Production Rate	141.86%	386.18%	1092.65%
Avg. Paver Utilization	146.05%	346.40%	881.29%

Table 6 shows an overall improvement of the model's performance when the model is changed to reflect zero time delivery. The improvements, however, affect the model in an opposite way to how the non value-adding activities did. Generally speaking, the percent improvement, as compared to the base model, increased as the haul distances increased. The reason for this is that as the haul distances increase, the amount of time required for material delivery increases as well. For large haul distances (if the number of haul trucks is kept the same), the room for improvement is also large. Figures 8, 9, and 10 display the velocity diagrams for each of the three haul distances.

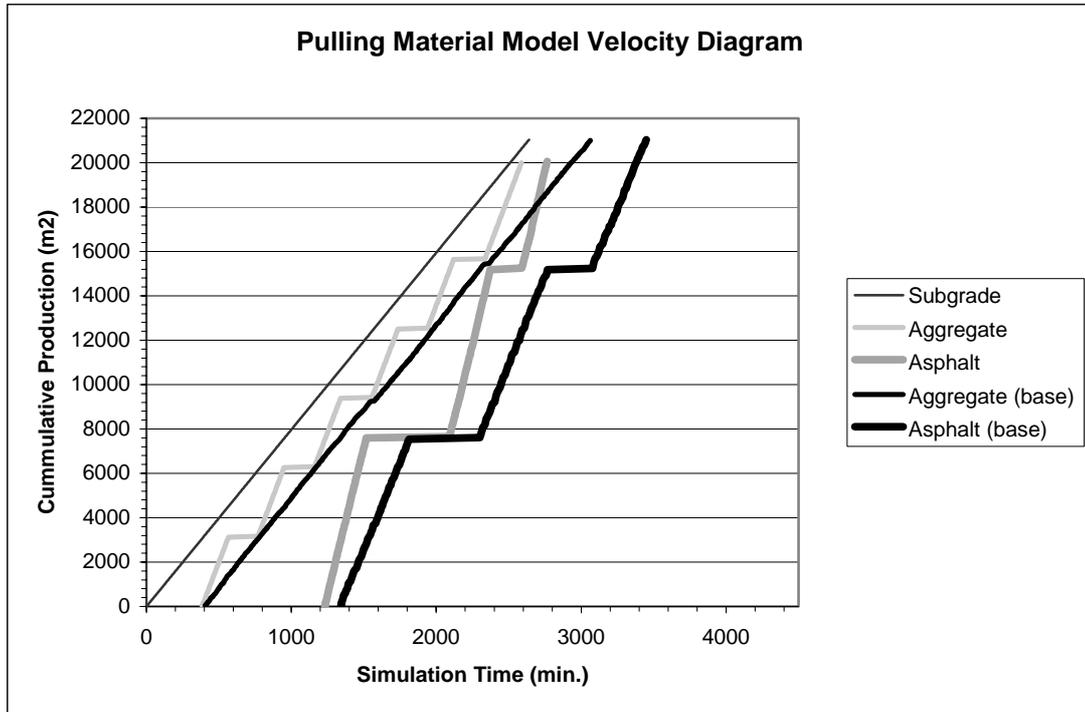


Fig. 8. Pulling material model vs. base model - velocity diagram (short haul, 5-kms)

Although the "pulling material" model experienced an opposite effect in terms of the reaction to haul distances, a similar effect was observed in terms of process variability. The aggregate operation, for example, was stopped due to operational interference with the subgrade process a total of 5 times (in both cases) compared with zero times in the base model (just as in the non value-adding experiment). This will be discussed in the next section, however it is clear that introducing the concepts of lean production increase the differences in the operational production rates. The data collected from this experiment indicates that in surface works operations, "pulling" rather than "pushing" material has the greatest effect on the process when the haul distances are long.

This step is the same as Step 5, except it applies to material delivery activities. In many cases it would be impractical to eliminate these activities from the process. It may be possible, however, to improve them by analyzing the process at a more detailed level. This exercise may include choosing better haul routes, selecting haul trucks with larger capacities, or brainstorming with suppliers to develop a new material delivery plan.

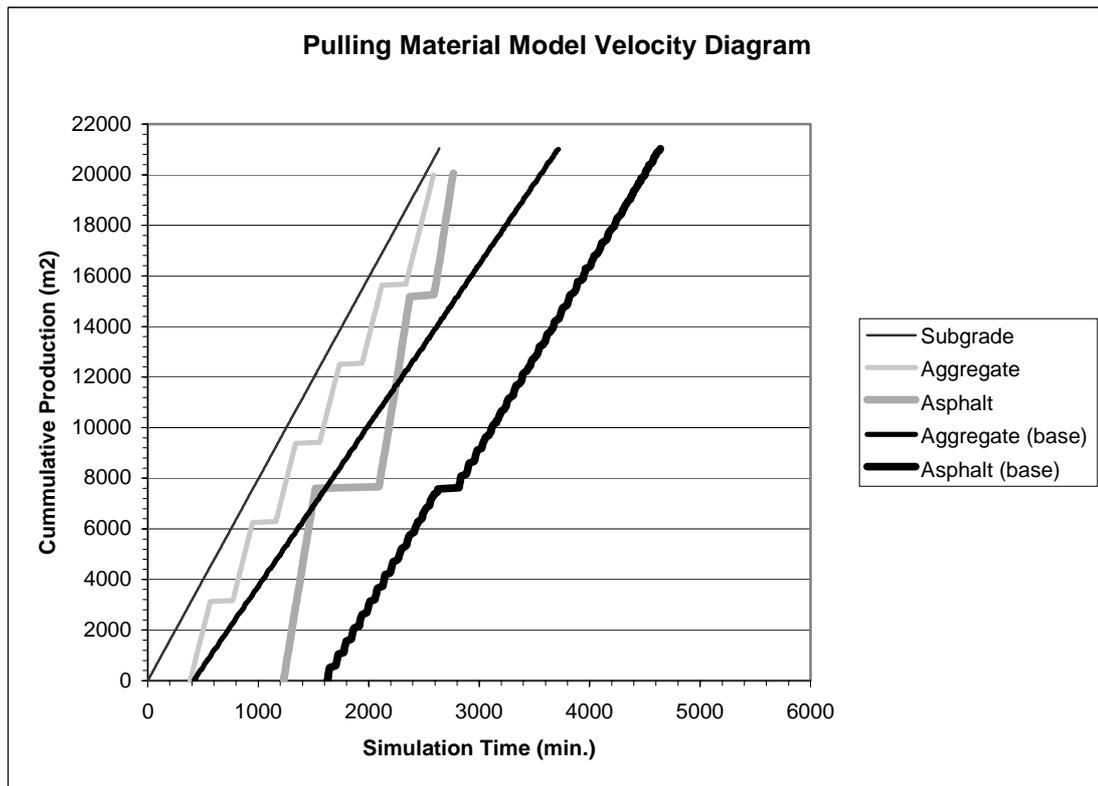


Fig. 9. Pulling material base model - velocity diagram (med. haul, 30-kms)

4.3.3. Create Reliable Flow

The results of changing the base model to reflect value-adding activities and zero-time delivery showed significant improvements with regard to production rates. However, the velocity diagrams shown in this section, demonstrate that operational buffers are required to control the impact that linked unbalanced operations have on one another. Howell et al. (1993) recommended that "once an operation is underway, isolating sub-cycles by establishing buffers and eliminating shared resources is the first step to performance improvement in uncertain and/or unbalanced situations". While buffers are certainly necessary in order to achieve a balanced system, they should not be the first step taken towards process improvement. The base model velocity diagram for the medium haul distance (Figure 6) depicts a fairly balanced system. The production lines of each operation are nearly parallel. As lean concepts were introduced, the processes within the model became unbalanced, resulting in operational interference. Therefore, it only makes sense to adjust the operational buffers only after the other lean concepts are introduced into the model; doing otherwise would be counter-productive. Buffer optimization can be done to reduce model variability by running the model several times and experimenting with differing buffer sizes.

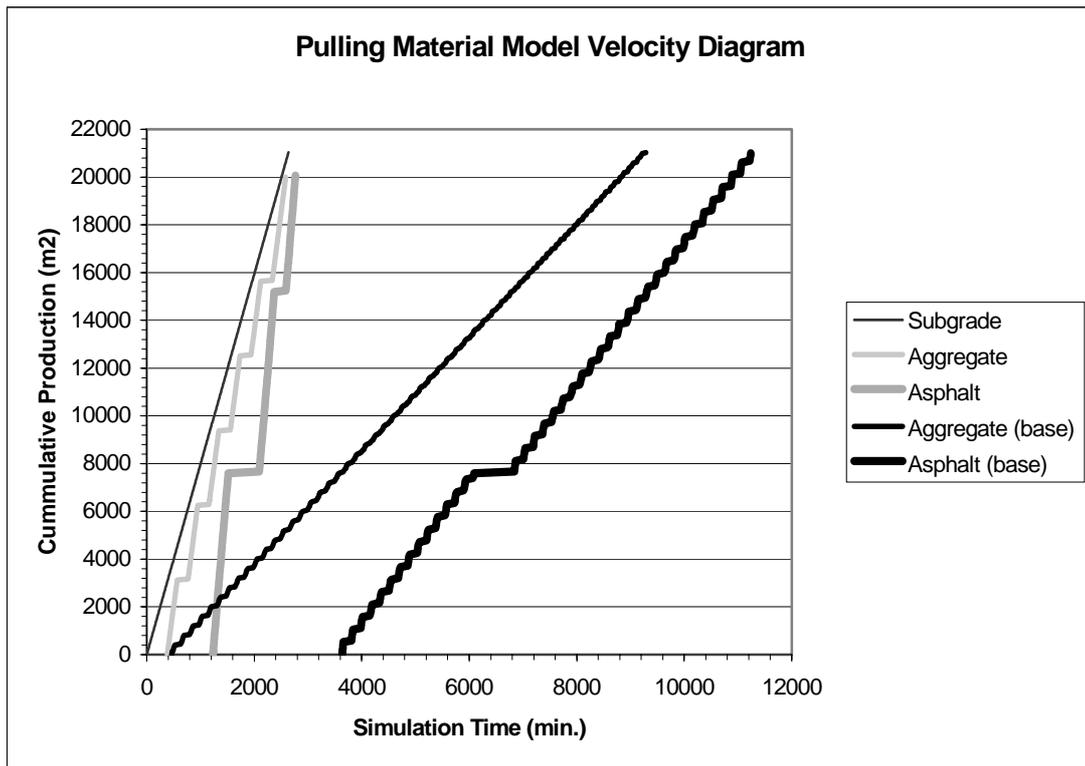


Fig. 10. Pulling material model vs. base model - velocity diagram (long haul, 100-kms)

5. Conclusion

The research contained in this paper ultimately presents a systematic approach for the application of lean production theory in computer simulation models. This is accomplished through development and experimentation using a special purpose simulation template designed for research in surface works operations of road construction.

The improvements demonstrated through the elimination of non value-adding activities and from the implementation of a methodology of pulling material through the process, were significant. The hourly production rate, resources utilizations, and project duration all improved dramatically, as a result of these implementations.

In terms of experimental findings, the effect of applying lean principles to the process was the most significant discovery. Sensitivity analysis using lean principles has shown that a process can improve significantly by focusing on non value-adding and material delivery activities and optimizing the use of buffers. Current thinking in the construction industry focuses improvement on activities that are directly linked with production; this experiment has shown that there is great improvement potential to be had by focusing on other aspects of the operation as well. This is also likely the case for processes other than road works.

An important feature of this work, which distinguishes it from other lean production / simulation experiments, is that it was accomplished using a SPS template. Other such experiments use stand-alone models to demonstrate lean principles. These models require both knowledge of computer programming and an understanding of computer

simulation techniques. The SWRC template is flexible enough to model many road construction projects, without the need for such specialized knowledge

Although the results of this experiment are specific to surface works operations, the generic approach used for implementing lean production principles is general enough that it could be used on any simulation model, regardless of the domain.

6. Research Contributions

This research has presented the following contributions:

- (1) The development of a systematic approach for the application of lean production theory in computer simulation models.
- (2) The development of a special purpose simulation template that can be used to create flexible computer simulation models of surface works operations in road construction.
- (3) Significant insight was gained as to how the key concepts of lean production theory can improve the surface works operations of road construction.

Lean production can be summarized into three main points:

- (1) eliminate or reduce all activities that do not add value to the final product,
- (2) pull material through the process (instant delivery of required materials), and
- (3) reduce variability by controlling uncertainties within the process.

Although the concepts of lean production have recently been introduced to the construction industry, only preliminary work has been done to integrate them with the concepts of computer simulation.

This paper presents a framework for implementing the concepts of lean production into computer simulation models. This framework posits the creation of a generic approach that practitioners can use to apply lean principles to any computer model regardless of the domain. This approach is important because it enables users to apply lean principles to simulation models and helps to bring them closer to applying these principles to actual construction projects.

In addition, this thesis describes the development of a special purpose simulation template for surface works operations of road construction (SWRC template). This SPS tool allows practitioners to create flexible models of surface works operations in road construction. Model outputs can be used to perform various analytical functions including model sensitivity analysis, scenario analysis, and lean construction theory analysis. The SWRC template has also been used to establish how lean production theory can be used to improve road construction operations significantly.

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Moving-on – beyond lean thinking

Lauri Koskela¹

Abstract

Lean Thinking is currently often positioned as the underlying theory of lean production among practitioners and academics, although its originators, Womack and Jones, seem not to have presented it as a theory. This paper endeavours to analyze whether Lean Thinking can be viewed as a theory of lean production.

For this purpose, a critical assessment of Lean Thinking is carried out. Lean Thinking is argued to lack an adequate conceptualization of production, which has led to imprecise concepts, such as the term “value”. The five principles of Lean Thinking do not systematically cover value generation, and they do not always encapsulate the core topics in their respective areas. The failure to trace the origin of lean concepts and principles reduces the opportunity to justify and explain them.

Despite claims for generality, the application area of the five lean principles is limited to the transformation of mass production, with, for instance, one-of-a-kind production and construction being largely out of scope. It is concluded that it is opportune to move on beyond Lean Thinking, towards a generic theory of production, for acquiring a solid foundation for designing, operating and improving production systems.

Keywords: Lean thinking, theory, production

Introduction

“Lean production is ‘lean’ because it uses less of everything compared with mass production: half the human effort in the factory, half the manufacturing space, half the investments in tools, half the engineering hours to develop a new product in half the time.”

This characterization of lean production, as presented in the book *The machine that changed the world* by Womack, Jones and Roos (1990), captured the attention of production practitioners and researchers worldwide. The description of lean production by Womack and his co-authors has proved to be a highly useful synthesis of advanced manufacturing practices, first developed at Toyota and later adopted by other car manufacturers. The very term “lean production” has become widely used for referring to a specific template and practice of production, also well known as the Toyota Production System.

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It is in this spirit that the founders of the International Group for Lean Construction started to use (or maybe coined, instances of prior usage are not known to the author) the term “lean construction” in 1993, for referring to a mode and practice of construction inspired by the Toyota Production System. As is well-known, research, development and implementation of lean construction has since then advanced and diffused to all continents.

However, since the late 1990’s, a subtle, but significant problem with the terms “lean production” and “lean construction” has emerged. It has become evident that many people do not associate these terms with evolutionary production templates developed or inspired by Toyota, but rather with the application of “lean thinking”, and especially the five principles of Lean Thinking² as presented by Womack and Jones (1996). Unfortunately, these five principles are a stark and to some extent imprecise simplification of the underlying theoretical framework of the Toyota Production System. The principles have excellently served a pedagogical and marketing function, but real life implementation, as well as further development of lean must - and can – be based on a wider set of ideas and frameworks. Thus, this paper argues that we have to move on, beyond this Lean Thinking oriented understanding of lean production.

The paper is structured as follows. At the outset, the origins and popular interpretation of Lean Thinking are analyzed. Next, the question whether Lean Thinking can be seen a theory in general is dealt with. Based on this consideration, Lean Thinking is then analyzed regarding conceptualization, validity of its principles, justification and range of applicability. Finally, conclusions are drawn from the preceding analyses.

Lean thinking

Origin

As admitted later by two of its authors (Womack and Jones 1996), the book *The machine that changed the world* did not concisely summarize the principles of lean production. In their newer book (1996), Womack and Jones endeavour to improve the theoretical side of the discussion of lean production. They say of the previous book: “...the thought process needed to tie all the methods together into a complete system was left largely implicit.” Further: “... we realized that we needed to concisely summarize the principles of “lean thinking” to provide a sort of North Star, a dependable guide for action for managers striving to transcend the day-to-day chaos of mass production.” Without such a guide, managers are drowning in techniques “without understanding the whole.”

Consequently, Womack and Jones (1996) summarize the principles underpinning Lean Thinking:

1. Precisely specify value by specific product.
2. Identify value stream for each product.
3. Make value flow without interruptions.
4. Let the customer pull value from the producer.

² In this presentation, Lean Thinking refers to the particular type of *lean thinking* proposed by Womack and Jones (1996) in their book with the same title. For clarity, the book title is written here in italics: *Lean Thinking*.

5. Pursue perfection.

As it is well known, the book *Lean Thinking* has been hugely successful, and this success has led to conferences and a community around the topic of Lean Thinking.

Interpretation

Lean Thinking is clearly a business book. To the best knowledge of the writer, its authors have never presented and justified the five principles of Lean Thinking as a theory³ in any academic journal. However, it seems that the very success of the book has led to misplaced views on Lean Thinking. It has been understood that the five principles provide an exhaustive, mature foundation - equivalent to a theory – for the transformation of any productive activity. For example, the Egan report (Rethinking construction 1998) stated:

“Lean Production is the generic version of the Toyota Production System, recognized as the most efficient system in the world today. Lean Thinking describes the core principles underlying this system that can also be applied to every other business activity - from designing new products and working with suppliers to processing orders from customers.”

A similar view has recently been taken in operations management (OM) literature (Slack, Lewis & Bates 2004):

“For instance, JIT/lean production is a long-established OM research priority that in recent years has probably become less prominent as a subject as the core principles have matured. In terms of practice however, there is still a great deal of scope for applying these, now clearly articulated and tested, principles - especially beyond their traditional manufacturing roots (e.g. Womack and Jones, 1994, 1996)”.

Similarly, Hines et al. (2004), while acknowledging the evolutionary nature of lean production, nevertheless claim that the principles have remained unchanged:

“Such a process of evolution has maintained the adherence to the lean principles developed by Womack and Jones (1996) but has explored different applications and contingencies faced by organizations during the adaptation ... process.”

Are the five principles of Lean Thinking valid as a theoretical foundation, in the way they seem to be understood in many circles? This question is not only academic but also highly practical. Namely, from an academic point of view, if this is the general theory, we can reduce our efforts to understand lean production, and we can concentrate on the issues of implementation. And from the practical viewpoint, we can fully trust that by using this theory, we can transform any line of production or service into a lean operation.

Is lean thinking a theory?

Theory is a slippery concept, with many connotations. In one sense, theory refers to general principles of any field or discipline. In this sense of the term, the question is surely about theory, and the assessment reduces to assessing the adequacy of the principles

³ It is true that Womack and Jones (2003) write in the Afterword: “Our problem in writing this book was never theory. Authors with academic backgrounds will generally have no trouble spinning theories, and this task happily occupied us during the first year of this project (1992-93). But then we needed proof that our theorizing actually works, examples of real managers in real firms who are succeeding by employing ideas similar to ours”. However, a close reading of this passage reveals that the authors do not claim to present their theorizing in the book in a systematic manner.

involved - this will be carried out below. However, in the more stringent sense of the term, a theory refers to a scientific theory. According to Whetten (1989) such a theory will contain four essential elements:

- **What.** Which factors (variables, constructs, and concepts) logically should be considered as part of the explanation of the phenomena of interest?
- **How.** How are factors related? Here, causality is introduced.
- **Why.** What is the rationale that justifies the selection of factors and the proposed causal relationships? An explanation is required.
- **Who, Where, When.** The boundaries of generalisability and thus the range of the theory have to be set.

Is Lean Thinking a scientific theory? Does it have the parts as suggested by Whetten?

Lean Thinking contains five principles, which at least implicitly present causal relationships: do this, so waste is minimized and value maximized. It thus contains the “How” element. However, other parts are either lacking or treated in a shallow or partial mode. There is no conceptualization of lean production, i.e. an answer to the “What” question. There is some justification for the principles, but not for the whole approach. Thus, the “Why” question has not been systematically answered. The “Who, where, when” issue is not tackled in any deeper sense, although one gets the impression that the principles are suggested to be generally usable.

Surely theories may be usable and widely diffused without being perfect in Whetten’s (1989) sense. He comments that the last element, the boundaries of the theory, is often the least developed area. Thus, the question is whether the failure to adequately present the “What”, “Why” and “Who, where, when” elements creates detrimental impacts.

Thus, Lean Thinking contains at least some elements of a theory, and these can be evaluated in the normal way by assessing their validity in comparison to empirical reality. However, regarding the missing or in some respect inadequate elements, we ask: In which way are we in a poorer position without those elements?

In the following section we start by inspecting the conceptualization of production (“What”). Then, we proceed to the evaluation of the lean principles (“How”). The way of tackling the “Why” issue is by looking at the historical development process, leading to the introduction of concepts and causalities in question. Lastly, we analyze Lean Thinking from the “Who, where, when” point of view.

Conceptualization of production

Concepts of production

The reader of *Lean Thinking* cannot avoid noticing that there are two central, allegedly new terms for analyzing production: *muda* (the word waste in Japanese) and value. However, it is not explained from where these terms originate.

In our view, these terms naturally flow from the concepts of production relied on. Even if there has been very little explicit research into theories of production, we can find three theoretical models of production (Koskela 2000). The most common view has been that

production is a *transformation* of production factors into the product. Another view is that production is a *flow* of material through the production system. The third view is that production is *value generation*, fulfilling the customers' needs and wishes.

The splendid feature of the transformation model is simplicity: it focuses just on what goes in and what goes out of production. Of course, productivity is a related term, being determined by input and output. Here, the first principle is to decompose the total transformation into smaller ones, usually called tasks, and to perform each of them in an optimal manner. Isn't this reasonable: we look at what has to be done, we do all that and production is completed? The crucial assumption here is the independence of these tasks. If it is evident that they are not independent, we can make them (relatively) independent by buffering them.

In the flow model, we introduce time as an attribute. When we look what happens to a piece of material in production, we observe that there are transformations, but also waiting, inspection and moving stages. The last three are not really needed for transformation, and they can be called waste. The first principle is to eliminate or reduce this waste. How can it be done? Already from the twenties it has been known that time compression leads to waste reduction (Koskela 2000, 68-9). A newer insight is that uncertainty (to be precise, variability, that is, random variation in the processing times or arrival of inputs) is an important cause of waste.

In the value generation model, the customer is introduced. The first principle is to create the best value for the customer. The pedigree of the value generation model goes back to Shewhart (1931), who defined two further principles of value generation at the outset of the quality movement:

Looked at broadly there are at a given time certain human wants to be fulfilled through the fabrication of raw materials into finished products of different kinds. [...]

The first step of the engineer in trying to satisfy these wants is therefore that of translating as nearly as possible these wants into the physical characteristics of the thing manufactured to satisfy these wants. [...]

The second step of the engineer is to set up ways and means of obtaining a product which will differ from the arbitrarily set standards for these quality characteristics by no more than may be left to chance.

There are two important insights here. First, it makes a difference which concept of production is used: depending on what basic concept you select, you end up with very different, even conflicting, prescriptions for production. For example, the transformation model suggests using buffers between workstations; the flow model suggests eliminating buffers. Second, terms such as 'productivity', 'waste' and 'value' are not independent, self-contained concepts - rather they are embedded in different conceptualizations of production, which provide their meaning.

Unfortunately, the conceptualization of production, i.e. an answer to the "What" question, is conspicuously lacking from *Lean Thinking*. Some of the problems caused are explored next.

The relationship of waste and value

Womack and Jones write: “Lean thinking also provides a way to make work more satisfying by providing immediate feedback on efforts to convert muda into value.” This suggests that value can be maximized through minimizing waste. Indeed, they define the eighth waste as design of goods and services that do not meet users’ needs (the first seven wastes being those defined by the Japanese originators of the Toyota Production System).

However, these two concepts, waste and value, are better thought of as existing in different, even if intersecting dimensions. A product with a wonderful value may be produced in a most wasteful process. On the other hand, a product with a clearly deficient value may be produced in a most waste-free process. Unfortunately, there is no such handy and direct connection between waste and value as indicated in Lean Thinking.

What is value?

Womack and Jones state: “The critical starting point for lean thinking is value. Value can only be defined by the ultimate customer.” This is a sensible characterization of value, which connects to more general use of the term.

However, when we start to inspect the lean principles, we readily realize that something is not in order (Table 1). Regarding the first principle: How can we specify value, if it is something happening between the customer and the product? We cannot. Obviously, value is used instead of the word product (or perhaps product features or functions) there. Then value is flowing in the value stream, and value is pulled at the end. Have we ever seen value flowing or being pulled in factories? No, we see only parts, materials and completed products. Obviously, in turn, value is here used to mean materials, parts or products.

Table 1: The many meanings of value in the lean principles

Lean principles	Inferred meaning of <i>value</i>
1. Precisely specify value by specific product.	1. Specify value = specify product
2. Identify value stream for each product.	2. Value stream = material (or information) flow
3. Make value flow without interruptions.	3. Value = parts, materials
4. Let the customer pull value from the producer.	4. Value = product
5. Pursue perfection.	

Now we are able to decipher the significance of the statement “...the thought process needed to tie all the methods together into a complete system was left largely implicit” (Womack & Jones 1996). Without an explicit theory of production as value generation, they just use the term value as glue that artificially keeps the principles together, indeed ties them together into a complete system. In doing so, they have to stretch the meaning of value excessively and misleadingly wide. Unfortunately, the frequent use of ‘value’ among the principles also conceals the fact that very little is said on how to maximize value.

Simply, the authors are using imprecise and unsystematic terms, due to lack of explicit conceptualization.

Assessing the principles of lean thinking

The following questions are posed for assessing the principles: What is meant by the principle? Does the principle encapsulate what we know about its theme area?

Precisely specify value by specific product

What is meant by the principle?

The central message of this principle seems to be to “rethink value from the perspective of the customer” and “to ignore existing assets and technologies”.

Does it encapsulate what we know?

That value should be rethought from the point of view of the customer is now a somewhat tired platitude (we return to this below). Instead, already Shewhart succeeded in defining two high-level principles of value generation, and there are candidates for three others (Koskela 2000). Unfortunately, none of these is treated as Lean Thinking⁴. But is this judgement premature, noting that value is explicitly mentioned in three subsequent principles? Unfortunately, “value” in the subsequent principles is a misnomer, as justified above. The first principle is the only one trying to cover value generation, but whether it does the job, is questionable.

Identify value stream for each product

What is meant by the principle?

The question is about the modelling and designing of the production system, including product development, order fulfilment and the production proper, especially with the goal of weeding out avoidable wasteful activities.

Does it encapsulate what we know?

At a high level of abstraction, this principle works reasonably well⁵.

Make value flow without interruptions

What is meant by the principle?

This principle, while addressing generally the reduction of lead times, refers primarily to the method of one-piece flow, instead of a flow consisting of batches.

⁴ This is understandable taking into account that value issues have historically been somewhat outside the Toyota Production System. Cell and Arratia (2003) state from a value engineering (VE) viewpoint: “Unlike VE, Lean has no analytical or methodological mechanism for analyzing the design of the product with the intent of reducing production cost or otherwise increasing customer value”.

⁵ Of course, it is not very explicit with the criteria of designing production systems, but this is due to a wider lack of understanding in this regard.

Does it encapsulate what we know?

Actually, there are several other conclusions from this principle than one-piece flow - they seem not to be treated. It can easily be shown through queuing theory that variability increases the lead time (Krupka 1992, Hopp & Spearman 1996) and thus work-in-progress. Thus, reduction of variability can be used as one important method of waste elimination. However, variability is not covered in *Lean Thinking*.

Let the customer pull value from the producer

What is meant by the principle?

According to the principle, the customer is pulling the product from the production system as needed rather than the production system pushing products, often unwanted, onto the customer.

Does it encapsulate what we know?

Push systems schedule the release of work, while pull systems authorize the release of work on the basis of system status (Hopp & Spearman 1996). The underlying feature of the pull systems, like kanban, is that they establish a cap for work-in-progress, which will also keep lead-time in control.

A production control system can also be a mixed push-pull system. Huang and Kusiak (1998) present a push-pull system that pushes through certain manufacturing stages and pulls elsewhere based on the characteristics of these stages. They argue that this is superior to a push system, while avoiding some inherent problems of pull systems. Thus, either push and pull method may be appropriate depending on the characteristics of the production stage in question. Accordingly, the wording of this principle is too categorical.

Pursue perfection

What is meant by the principle?

Womack and Jones say, "there is no end to the process of reducing effort, cost, and mistakes while offering a product which is ever more nearly what the customer actually wants" (1996). Obviously, the question is about continuous minimization of waste and maximization of value, i.e. continuous improvement.

Does it encapsulate what we know?

The principle is defined on a very general level. The book rightly mentions transparency as one of the most important spurs to perfection. Unfortunately, the role of standards (Nakamura 1993) is not treated in connection to continuous improvement. Neither is the scientific experimentation model of Shewhart mentioned (to be discussed below).

Assessment of the principles as a whole

Womack and Jones (1996) write: "By clearly understanding these principles, and then tying them together, managers can make full use of lean techniques and maintain a steady course."

Unfortunately, there are problems here. Indeed, the authors cover a number of crucial principles or practices related to the flow concept; the treatment is selective, however, and several key issues are left out⁶. Moreover, the value generation concept principles are left almost without mentioning. How the transformation concept is used in lean production is not discussed at all.

A related problem is that there is a gap between the first principle, addressing product specification, and the following three principles, addressing, in practice, production. It is to be assumed that product development has somehow been completed between the first and second principle.

All in all, it is highly questionable whether all principles, in their starkly compressed form, can be understood in a productive way and whether they come together to a whole.

Justification of the lean principles

Why should we think that just these principles should be adopted? In principle, several ways of justification can be used. However, if the question is about an existing idea or practice, a natural way is to seek for a justification from the situation where the breakthrough of the idea or practice happened. So, the question, from where do the principles originate and what was the related rationale, poses itself.

Specify value

The first principle, in the meaning “rethink value from the perspective of the customer” and “to ignore existing assets and technologies” is well known in the American marketing literature. In 1960, Levitt attacked the then prevailing production paradigm:

Mass-production industries are impelled by a great drive to produce all they can. The prospect of steeply declining unit costs as output rises is more than most companies can usually resist. The profit possibilities look spectacular. All effort focuses on production. The result is that marketing gets neglected.

The difference between marketing and selling is more than semantic. Selling focuses on the needs of the seller, marketing on the needs of the buyer. Selling is preoccupied with the seller’s need to convert his product into cash, marketing with the idea of satisfying the needs of the customer by means of the product and the whole cluster of things associated with creating, delivering and finally consuming it.

...a truly marketing-minded firm tries to create value-satisfying goods and services that consumers want to buy.

⁶ One may ask whether it is possible, in general, to condense lean production into five principles. In comparison, Schonberger (1996) presents sixteen principles for world class manufacturing, which seem to largely cover the area of the five lean principles but go beyond them. On the other hand, there are areas, such as the value stream mapping, where lean principles seem to present new insights in comparison to Schonberger’s treatment.

Of course, Levitt's views are fully compatible with Shewhart's value generation model, explained above. There is nothing wrong in reminding people of these often neglected ideas, even if they have not figured prominently in the framework of the Toyota Production System. However, many a reader of *Lean Thinking* might have benefited from connecting this idea to its roots and related previous discussions.

Value stream, flow and pull

The three middle principles can be discussed together, as they all are original features of the Toyota Production System, discussed in the books of Ohno and Shingo as well as in the first Western interpretations (for example, Schonberger 1982).

The origin of the second principle might be in the flow oriented principles for designing the factory layout. In addition, this is an area where the re-engineering movement operated during its heyday. It must be added that the idea of modelling production processes has even deeper roots. Frank and Lillian Gilbreth (1922), in a paper advocating process modelling, refer to practices that obviously resemble value stream mapping:

In many instances recording industrial processes in process-chart form has resulted in astonishing improvements.

Similarly, the third principle, focusing on one-piece flow, is one of the issues addressed early by the Japanese originators. The fourth principle on pulling seems to derive from the kanban production control, an original invention of the Toyota Production System.

Again here, the discussion and justification of these principles would have had more depth if the roots had been covered.

Perfection

The fifth principle addresses continuous improvement. In the West, continuous improvement, associated both with JIT and TQC, emerged as a theme in itself especially after the book by Imai (1986). A key idea is to maintain and improve the working standards through small, gradual improvements. The inherent wastes in the process are natural targets for continuous improvement. However, even in this case there is an important predecessor. Shewhart (1931) presented the idea of the scientific experimentation model, which has functioned as the basis of the introduction of continuous improvement in total quality management, and still can be recognized as a backbone in the current Japanese implementation of the Toyota Production System, as described by Spear and Bowen (1999).

Unfortunately, without presenting the seminal idea of Shewhart on continuous improvement, only the superficial appearance of continuous improvement is conveyed and shallow justification of it is provided to the reader.

Range of applicability

Womack and Jones (1996) write: "As the examples will show, we know how to apply lean thinking, techniques and organization to practically any activity, whether a good or service." So, although the main focus is on transforming mass production, it seems that the authors more or less view Lean Thinking as a generic approach, appropriate for any

activity. Let us test this by looking at another significant type of production, one-of-a-kind production, and its one special case, construction

One-of-a-kind production is characterized by the necessity of including the product design stage in any consideration of production. Product design accentuates the issues related to value generation. What support does Lean Thinking give for ensuring that value is maximized? Very little, because, as argued above, value generation is not covered by the principles, except for a most narrow part by the first principle.

Let us focus on a specific type of one-of-a-kind production. Let us assume one-of-a-kind production with temporary location and temporary organization. Construction is the classic example of this. We realize that practically all the principles are in great trouble⁷. The client is certainly pulling the end product, but the production system is built up along with the facility to be built, and there might be nobody to pull at site on Monday morning when a certain work should start - if there is no downstream workstation that could pull! Rather, inputs emerge there and the work starts because they have been scheduled to do so, i.e., they are pushed. Work is done in temporary locations all over the facility, and it would be most challenging to create neat production cells where material or intermediate products would flow in one piece mode from one work station to another. What is the meaning of continuous improvement when the production system will anyway be dismantled, the organization disintegrated, and any improvement will be swept away like dust by the wind?

The conclusion is that Lean Thinking is deeply contextual⁸; it has been formulated in the context of mass production with repetitive activities, occurring in permanent locations, with permanent organization.

But there is a more profound problem. Production of discrete products in large quantities is an ordered activity, with small uncertainty, barring demand fluctuations. However, product development or design cannot be characterized in this way, rather they fall into the category of complex, adaptive systems. It has been argued that even some types of physical production, such as construction, can better be seen as a complex adaptive system (Bertelsen 2004). *Lean Thinking* does not address this kind of phenomenon, which obviously requires different managerial approaches⁹.

The conclusion is that Womack and Jones' failure to address the "Who, where, when" issue led them to imply general applicability of the five lean principles. The evidence does not support that.

⁷ The following arguments are not meant to discourage the application of lean ideas in construction; rather they try to show that another set of principles is needed for construction. For example, the author has argued (Koskela 2004) that the principle of avoiding making-do is of great significance in construction. Making-do refers to negative buffering: an activity is started before all its inputs are at hand.

⁸ Koenig *et al.* (2002) provide further evidence for this standpoint. They claim that not all lean principles are applicable to Japanese shipyards. Moreover, they view that the Japanese shipbuilding industry likely ranks ahead of Toyota in terms of achievement of lean production. In a similar vein, Hines & al. (2004) write: "In particular when applied to sectors outside the high-volume repetitive manufacturing environment, lean production has reached its limitations, and a range of other approaches to counter variability, volatility and variety have been suggested."

⁹ This is not to argue that the underlying ideas of lean production could not be applied to situation involving complex, adaptive systems. However, the methods must be adapted from the first principles rather than transferred from a different setting.

Conclusions

What should the final assessment regarding Lean Thinking be? In its original role, as a popular introduction into lean production, *Lean Thinking* is admirable. The principles are conveniently compact and surprising enough for captivating the imagination and providing inspiration. The success of the book and its implications, in the form of conferences and institutionalizing of the community around Lean Thinking, prove that the principles have helped practitioners to absorb central ideas of lean production and to start the transformation of mass production into lean.

However, this very success seems to have led to misplaced views on Lean Thinking in many circles. It has been understood that the five principles provide an exhaustive, mature foundation for the transformation of any productive activity. However, analysis shows that *Lean Thinking* provides only fragments, albeit important ones, of the universe of existing understanding.

Especially, *Lean Thinking* lacks an adequate conceptualization of production, which has led to imprecise concepts, such as the term “value”. The five principles of Lean Thinking don’t systematically cover value generation, and they do not always encapsulate the core topics in their respective areas. The failure to trace the origin of lean concepts and principles reduces the opportunity to justify and explain them. Despite claims for generality, the application area of the five lean principles is limited to the transformation of mass production, with one-of-a-kind production and construction, for instance, being largely out of scope.

Thus, unfortunately, analysis shows that Lean Thinking cannot be viewed as a valid and mature theory of production¹⁰. Now it is opportune to go forward, towards a generic theory of production, for acquiring a solid foundation for designing, operating and improving production systems.

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¹⁰ It must be emphasized once more that the assessment of Lean Thinking as theory does not do justice to the book with the same name - very much liked by the writer. It is a business book where lean manufacturing is popularized, and it has no ambitions to be a scientific treatise on the subject. For example, it does not try to trace the intellectual history of lean production, or to relate these principles to other principles of production management, in difference to any academic treatment of the subject.

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COMPETING CONSTRUCTION MANAGEMENT PARADIGMS

Glenn Ballard and Gregory A. Howell¹

Abstract

The Lean Construction Institute's (LCI) goal is to develop and deploy a new way of thinking about and practicing project management. Projects are conceived as temporary production systems, to be designed in light of the relevant 'physics' of the task to be accomplished. It is claimed that complex, quick, and uncertain projects cannot be managed in traditional ways. Detailed CPM schedules, after-the-fact tracking, earned value analysis, and competitive bidding are inadequate to the challenge of today's dynamic projects.

There are four roots of this Lean Construction approach: success of the Toyota Production System, dissatisfaction with project performance, efforts to establish project management on a theoretical foundation, and the discovery of facts anomalous (impossible to explain) from the perspective of traditional thinking and practice. The last of these four is explored in this paper, which presents the current state of construction management thinking as one of conflict between competing paradigms.

Keywords: construction management, flow, lean construction, paradigm, production system, project management, theory, value, variability, work flow, work flow variability, work structuring

Introduction

Lean Construction can be understood as a new paradigm for project management. Thomas Kuhn's famous account of how science develops through periodic conceptual revolutions (Kuhn, 1962) also describes the change from mass to lean manufacturing, and the parallel change from traditional to lean project management. According to Kuhn, periods of revolutionary change begin with anomalies that the established paradigm is unable to explain, leading eventually to the development of a competing, and ultimately victorious new paradigm. One of Kuhn's well known examples: the Copernican revolution changed cosmology from geocentric to heliocentric at a time long before empirical tests could decisively settle the question because the traditional paradigm had become clumsy and convoluted.

Lean Construction had three initial sources of inspiration, the impact of which has been bolstered by dissatisfaction with the practical accomplishments of project management. Koskela (1992) challenged the industry to apply the principles behind the revolution in manufacturing, and quickly initiated an effort to establish production management on a

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sound theoretical foundation. The third source took the form of an anomaly discovered by Ballard (Ballard & Howell, 1998); namely, that normally only about 50% of the tasks on weekly work plans are completed by the end of the plan week. This proved to be an uncomfortable fact for a philosophy of project management that relied on detailed, centralized planning and the assumption that what SHOULD be done could be transformed into DID through contract structures and contractual enforcement.

This paper proposes to view Lean Construction as a new paradigm challenging traditional thinking about construction and project management. A section on the historical and theoretical background is presented first, followed by sections on the pivotal anomaly, sections presenting current phenomena in construction management from a Kuhnian perspective, and finally speculation regarding what happens next.

Background

What are the key characteristics of Lean Construction? First of all, it conceives a construction project as a temporary production system dedicated to the three goals of delivering the product while maximizing value and minimizing waste. Koskela has explained in detail how this differs from the traditional conception of a production system which sees only the single objective of product delivery; i.e., fulfilling contractual obligations (Koskela, 2000). This is also quite different from conceiving a construction project as an investment made in expectation of return, which while not entirely inappropriate, abstracts away from the messy business of designing and making².

Designing and making products the first time is what construction projects are all about and puts them firmly in the same class with other project based production systems; e.g., shipbuilding, movie production, software engineering, consumer product development, etc.

This production management approach to projects brings with it some key concepts, among the most important of which are value, flow, and pull. Value is understood as a production concept, not an economic concept. Consequently, expressions like 'value for the money' are replaced with expressions like 'value is provided when customers are enabled to accomplish their purposes.' Value in this latter sense has no necessary connection to cost.

Flow, the movement of materials and information through networks of interdependent specialists, is almost invisible to those who see through the eyes of traditional project management. We all were educated to see resource utilization. Are workers busy? Are crane hooks loaded and swinging? But we were not educated to see work flow; e.g., to understand the various types of buffers, to select the right type of buffer for a given situation, and to locate and size those buffers to perform their tasks of absorbing variability and rebatching. One of the contributing factors to this myopia may well be the inability of individual project participants to act at the level of the entire project.

Parker and Oglesby brought industrial engineering into construction with the publication of their *Methods Improvement for Construction Managers* in 1972. However, their focus was on the individual operation, on the activities performed to transform materials and

² One of the interesting areas for future exploration is the relationship between the conceptualization of projects in terms of economics and in terms of production. This is both a theoretical and a practical question: Can projects be structured such that the pursuit of product delivery, value maximization, and waste minimization is in the business interests of all parties?

information into desired products. Consequently, many of us have had the experience during our careers of improving the performance of individual operations, but not improving the performance of the project. We were acting on the specialist, but not on the flows between specialists.

Those flows vary. Things arrive early or late. The production of output of the same sort takes more or less time. This variability makes it difficult to match load and capacity; i.e., to prevent work waiting on workers and to prevent workers waiting on work. Consequently, productivity and progress are impacted by work flow, even if construction methods are adequate.

Toyota developed pull mechanisms in response to this problem of work flow variability in manufacturing. Kanban cards were used to signal supplier workstations to deliver needed items, rather than pushing inventory onto the customer workstation whether or not it was needed. When load is placed on a specialist based on the project schedule, without regard for the readiness of the specialist to perform that work or for the readiness of the work to be performed, that is push, which is the characteristic mechanism employed by traditional project management; for example, when detailed master schedules are used as control standards. By contrast, when assignments are required to meet quality criteria for definition, soundness, sequence, and size, as in the Last Planner system (Ballard, 2000b), that is an instance of pull. Pull is also used in the form of backwards pass team scheduling (Ballard, 2000a), which produces phase schedules intermediate between milestone master schedules and the make ready process with which production control begins.

The anomaly

Traditional project management assumes that variability in work flow is outside management control and so does not attempt to systematically reduce variability. Rather, contingencies of various sorts are used in an attempt to accommodate or absorb this external variability within the limits of budgeted time and money. An additional, implicit assumption is that variability is spasmodic and small, making it more plausible that its effects can be absorbed through budget and schedule contingencies.

In 1993, Howell, Laufer, and Ballard published two papers quite outside the normal bounds of the construction management literature. In the first (Howell, et al., 1993a), the central concept was the combined impact of work flow variability and dependence, and their implications for the design of operations. The central concepts in the second paper (Howell, et al., 1993b) were uncertainty in project ends and means.

In 1994, Ballard and Howell (Ballard, 1994; Ballard and Howell, 1994; Howell and Ballard, 1994a and 1994b) began publishing measurement data on work flow variability. The first data showed a 36% plan failure rate; i.e., 36% of assignments on weekly work plans were not completed as planned. Later publications (Ballard and Howell, 1998) expanded the data set, revealing a 54% grand average plan failure rate over a wide range of projects and project types.

This data represented a paradigm-breaking anomaly for traditional project management. Variability was in fact not spasmodic but persistent and routine. Neither was it small. What's more, analysis revealed that the large majority of plan failures were well within contractor control, contradicting the traditional assumption that variability was from external causes. The failure of traditionalists

to actively manage variability became visible as a failure, as did the corresponding need for active management of variability, starting with the structuring of the project (temporary production system) and continuing through its operation and improvement.

Table 1: Work Flow Reliability Data (from Ballard and Howell, 1998)

Contractor 1	33 %
Contractor 2	52 %
Contractor 3	61 %
Contractor 4	70 %
Contractor 5	64 %
Contractor 6	57 %
Contractor 7	45 %
Average	54 %

Talking through each other

Kuhn said that advocates for competing paradigms typically 'talk through each other' because they are each operating within their own paradigms (Kuhn, 1972, p.109). That appears to be happening in the field of construction management today. For example, a recent criticism of lean construction³ interprets the expression 'reliable work flow' to mean that the same amount of work is performed by construction crews in successive time periods, then finds contradictory data on examination of actual projects, and advocates a return of research focus to resource productivity as opposed to work flow reliability. The primary defense of the Lean Constructionists is that the concept is misinterpreted and that the critics are flogging a dead horse. There is no intent to reinstate that debate here, but rather to see it as an instance of 'talking through each other'.

Disagreements over terminology are the natural consequences of competing paradigms. Let us consider in that light some terms central to the discipline of project management; namely, project, management, and control.

Project

We have already seen that the opposing camps have different conceptualizations of a project. Adherents of the old paradigm conceive a project in terms of delivery in conformance to contracts, neglecting waste minimization and value maximization goals. Failure to agree on the very object of study offers little prospect of agreement on anything else. cursory examination of some other key concepts substantiates that expectation.

Management

The competing concepts of management can be expressed in terms of Johnson & Broms' (2000) dichotomy between Management-by-Results (MBR) and Management-by-Means (MBM). MBR would have managers establish financial targets and monitor performance

³ That Lean Construction is drawing fire is perhaps an indication that it is beginning to be perceived as a threat)

against those targets. Financial measures are used to evaluate and correct production processes. MBM would have managers create and maintain the means or conditions for sustained organizational performance, relying on process measures for feedback on system performance. Johnson and Broms present Toyota as one of the exemplars of MBM, suggesting that the 'lean thinking' originating with Toyota has roots and implications well beyond manufacturing management alone.

MBR conceives management as consisting of goal setting before the act of production, monitoring during the act of production, and correcting after the act of production. The MBM concept of management by contrast has production system design before, system operation during, and improvement after the act of production, with operating itself divided into goal setting, controlling (in the active sense of steering), and correcting (see also Koskela, 2001).

Control

Traditionalists conceive control in terms of after-the-fact variance detection, while the Lean Constructionists conceive control in terms of active steering of a production system or project towards its objectives. This can clearly be understood as a consequence of the MBR and MBM concepts of management. Some in the Lean Construction camp are now questioning whether after-the-fact measurement will any longer be needed if production system design and operation are mastered.

Changing common sense

Following Kuhn, we should also expect to see a change in what counts as common sense. Kuhn illustrates that with an example from the heliocentric/geocentric conflict, noting that there was no need to explain why bodies fell toward the earth as long as the geocentric view prevailed, along with the Aristotelian notion of essences or natures. Things made of earth naturally sought the earth, while things made of fire naturally went upwards. A fundamentally different concept of matter and of ontology underlies the seemingly unrelated shift from an earth-centered to a sun-centered view of the cosmos.

An example of common sense from the Traditionalist camp of project management might be the following claim: If we do every bit of work as soon as possible, we will finish the project as quickly as possible. Lean Constructionists note that the truth of this common sense claim depends on the patently false assumption that the bits of work are independent. Traditionalists might reply that they very well understand dependence and in fact encapsulate dependence in CPM schedules. This provokes a rebuttal from the Lean Constructionists and the dance goes on as long as the participants have the energy to continue arguing. Common sense from the Lean Construction perspective might be illustrated with the rule that we first go for plan (work flow) reliability, then go for speed; reminiscent of the ancient fable of the tortoise and the hare.

Will lean construction be victorious?

Not all challengers to existing paradigms successfully seize the crown. What should we expect for Lean Construction? Bearing in mind that the authors are wildly prejudiced on this issue, we venture the opinion that Lean Construction will displace Traditional thinking about project and construction management.

There are many bits and pieces that together may prove persuasive, though, of course, time will tell. First of all, existing project management thinking is not theory based. Indeed, some Traditionalists appear to believe that project management cannot be founded on theory because the decisions of project managers are so much conditioned by context. In this regard, the theoretical foundation advanced by Lean Construction clearly has the upper hand. If a theory-based alternative can be shown to be plausible, it will ultimately be embraced. The alternative is to be restricted to a craft-type discipline, in which one can only learn from a master, who can only show what to do in specific circumstances, but cannot explain why what is done is effective.

A preponderance of evidence will potentially shift the weight of 'public' opinion (the relevant stakeholders in the discipline). That evidence is building rapidly. For examples, see the proceedings of the annual conferences of the International Group for Lean Construction at www.vtt.fi/rte/lean. Lean Construction is now an active force in the United States, United Kingdom, Denmark, Finland, Australia, Brazil, Chile, and Peru. Implementation also has begun in Singapore, Indonesia, Ecuador, and Colombia. Consider but one example: Graña y Montero, one of the largest engineering/construction

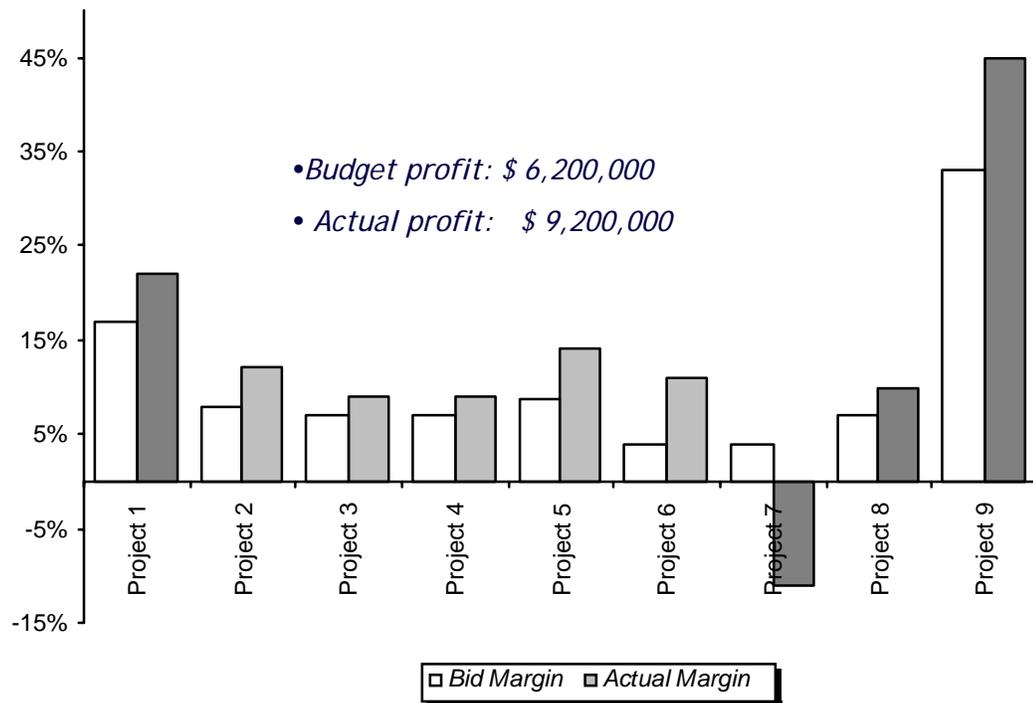


Figure 1: GyM Profitability Improvement⁴

contractors in Peru. Figure 1 shows the actual versus estimated gross margin (operating profit) on the first nine projects on which they employed a Lean Construction approach. Profit increased by \$3 million, from \$6.2 to \$9.2 million. This is but one example of many. Performance measurement is revealing the same magnitude of improvement as seen in

⁴ from a GyM presentation to the Lean Construction Institute at their AID Project in Lima, Peru in July, 2001.

earlier revolutions in production thinking; e.g., the Ford System in the 1910s and 20s and the Toyota Production System in the 1970s and 80s.

Success in the market is a key factor in the ascendance of technological concepts and techniques such as Lean Construction. The Lean Construction Institute has been working for several years with a small number of member companies, helping them develop their business capabilities while advancing its own research agenda. These companies, and others implementing Lean Construction tools, have shown significant success in their marketplaces. For examples, see reports by industry practitioners made at the Lean Construction Institute's annual Congresses at www.leanconstruction.org.

What happens next?

Looking at the situation through Kuhnian eyes, we can expect continuing clashes of the paradigms, a progressive ascendance of the new paradigm as it extends its critique of the old, demonstrates its theoretical and practical power, and gains adherents. Most of the old guard will retire or die like Joseph Priestly, the famous chemist who, despite his brilliance and contributions to chemistry under a previous paradigm, was never able to accept the new oxygen-based theory of combustion (Kuhn, 1972, p.56).

Dismantling the old paradigm will continue the onslaught begun with attacks on detailed central planning, after-the-fact variance detection, the earned value method of progress measurement, competitive bidding, and private ownership of the means of variability management; i.e., buffers such as schedule and budget contingencies, inventories, and capacities.

Numerous research projects are underway around the world on a variety of lean construction topics, some developing the paradigm, while some are of the "problem solving" variety Kuhn associates with "normal science":

- multiskilling
- learning to work near the edge (safety)
- management of continuous flow processes
- lean design of fabrication processes
- reducing lead times for engineered-to-order products
- structuring work for value generation
- target costing
- worker control of operations to process design versus managerial control of operations to budgets
- controlling work flow in design
- minimizing negative iteration in design

This trend appears set to accelerate as lean construction concepts and questions become better known. As we are led to expect from the history of such revolutions in other arenas, the young (in spirit) are in the front lines, while those successful under the old paradigm lag behind, clinging to the assumptions and methodologies that made them successful.

Acknowledgments

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LEAN CONSTRUCTION: WHERE ARE WE AND HOW TO PROCEED?

Sven Bertelsen¹

Abstract

This paper is written in the light of the papers for the 12th annual conference in the International Group for Lean Construction. It tries to establish a brief overview of the development over the past twelve years and to establish the state of the art. From this its primary objective is to open a discussion of the future effort within the Lean Construction environment. The paper proposes that a change in the underlying paradigm is happening and that a new research agenda should be established with an outset in the lean understanding of the construction process as it is known from the construction sites and with a complex systems understanding of the nature of this process. Elements in this agenda are outlined and areas for research identified within the areas of maximizing value for the client, minimizing waste in delivering this value, and managing the project delivery.

Key Words: Lean Construction, complexity, management, value, waste

Introduction

This paper has been written while reading the papers presented for the 12th annual conference in the International Group for Lean Construction, which was held in Elsinore, Denmark, 3-5 August 2004. Its basis is therefore the papers presented for this and for previous IGLC conferences mainly. By this the paper tries to establish a state of the art within Lean Construction, even though it is probably biased towards the Danish implementation of the lean principles.

It sets out to reach a deeper understanding of the nature of construction. It does so from a firm belief that construction is a special kind of production in its own right and that this kind of production is of great importance for the build environment. Not all production generating buildings is construction, and these days we see more and more of the output from such productions as part of our environment. This change in construction from offering a process to delivering a product is discussed in the terms of two strategies for the development of the construction process. Next the nature of the construction process as a craft based production is discussed from a complexity perspective and the paper proceeds to propose a 'construction physics' as an understanding of construction as a production in its own right. Finally some aspects of a new understanding of construction management in the light of projects' complexity are discussed.

The objective of the paper is not to open a discussion on architecture or on the build environment in general within the Lean Construction society, but to investigate the properties where construction distinguishes itself from manufacturing and to identify some areas for future research of importance to help keeping the - compared to

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manufacturing - less efficient construction process alive as an instrument in generating works of art.

Setting the New Agenda

Improving the productivity in construction is a great challenge facing the construction industry. In many countries the growth in its productivity is much lower than in manufacturing - if there is any growth at all - and as construction in most countries accounts for app 10 percent of GNP - or in Denmark for as much as 25 percent of all production in terms of employees - this is not an acceptable situation for any national economy (Byggepolitisk Task Force, 2000). In an age of efficient manufacturing, construction is therefore very much in focus as an industry where performance improvement - even at a small scale - may have significant impact on the national economy. An Australian analysis of the impact of a ten percent productivity improvement in various service sectors showed that construction had by far the most impact at 2.8 percent on the gross national product and further 1.2 percent if Domestic Housing was included (Stoeckel and Quirke, 1992).

More specifically the demand for improvement in construction is to provide higher quality in the output and reducing the costs, offer a better process to the client, and increase working conditions and safety (Latham, 1994; Egan, 1998; Byggepolitisk Task Force, 2000).

To a growing group within the industry Lean Construction seems to be the best way so far in reaching these goals.

The Nature of the Construction Industry

A Danish study (Erhvervsfremme Styrelsen, 1993) divided the construction sector into two parts: The *Construction part* and the *Industry part*. It did so recognizing that a development of the construction industry productivity as a whole would be difficult as it would call for different means. Development of the Industry part was supposed to take place through market mechanisms and if the productivity had to be improved further, a more efficient market for the products in the Construction part should be established. On the other hand, a development of the Construction part would call for a number of public initiatives, which gave rise to a series of development programs, which again have made the Danish construction industry aware of Lean Principles, Value Management, and cooperation and learning as the basis for a new kind of construction management.

Lean Construction: A Brief History

Lean Construction is to a great extent an adaptation and implementation of the Japanese manufacturing principles within the construction process and in doing this Lean Construction assumes that construction is a kind of production albeit a special one.

Even though the guiding principles were not formulated until after nearly ten years of work by Koskela (2000) and formulated in more detail in 2001 by Ballard et al (2001), one may easily deduce that from the beginning they were: *While delivering the project, maximize the value for the client and minimize the waste.*

Koskela (1992 and 2000) proposed - based on the development of manufacturing theories over more than a hundred years - the Transformation-Flow-Value (T-F-V)

understanding of construction. Koskela and Howell (2002) suggested that the flow aspect should be given more attention in construction management in lieu of the current overemphasis on the transformation aspect.

The production theory for construction proposed by Koskela and not least the concept of production as a flow showed almost immediately its usefulness by practitioners rethinking the construction management methods (Ballard 1993, 1994, 1997 and 2000) and later the management principles (Koskela and Howell, 2002; Bertelsen and Koskela, 2002). Ballard's groundbreaking work on the Last Planner System² method has showed an efficient way of understanding and not least managing the flow aspect of the construction process and to many within the industry Last Planner is synonym for Lean Construction - which it is not of course.

The concept of flow management was taken even further by using the methods introduced by Jim Womack and further developed by the Lean Enterprise Institute (Womack and Jonès, 1996; Rother and Shook, 1999). Not least the work undertaken at Berkeley by Iris Tommelein and Glenn Ballard (Holzemer et al, 2001, Ballard et al 2002, Elfving et al 2002, 2003 and 2004, de Alves et al 2004), has given a useful understanding of the room for improvement within the more ordered part of the construction process - the industry part - mainly, but also in the use of buffers and in the interplay between the ordered world of components manufacturing and the complex world of the construction process.

Around the same time that Koskela proposed the manufacturing-inspired T-F-V theory, voices were raised that the construction process might be even more complex and that it should be understood in a completely new perspective as well. Gidado (1996) presented a study of project complexity and suggested a numeric method for analyzing the complexity. Radosavljevic and Horner (2002) discuss evidence of complex variability in construction in which they found analogies to the pattern found in complex, dynamic - or chaotic - systems, and Howell and Koskela (2000) led a similar discussion at the 8th annual conference International Group for Lean Construction albeit without much attention from the audience. Inspired by this discussion, Bertelsen (2002) reiterated the idea that construction must be understood as a complex and dynamic system and later presented a broader study of its complexity (Bertelsen 2003a and b).

Koskela and Howell (2002) suggested that construction management as - one of several understandings - is understood as a scientific experiment. By this they accepted the unpredictable nature of the construction project, which indeed is a general characteristic of any complex system. But this acceptance of construction as a complex and dynamic system has much deeper implications for the future development of the Lean Construction principles as it challenges the underlying production theory, which is inspired by the ordered and foreseeable world of manufacturing mainly.

The challenge stems from the difference between the two types of systems - or rather from the two states as the terms: ordered and chaotic³ expresses. In a mainly ordered system order can be increased by reducing variability and disorder controlled with for

² Last Planner System™ is a trademark of Lean Construction Institute

³ In this paper the term chaotic is used in the mathematical/physical meaning: "deterministic unpredictable" that is that small differences in the outset do not stay small after a limited number of steps.

instance diligent use of buffers, well defined processes and procedures, and elimination of sources for errors. Chaotic systems on the other hand must be managed based on principles such as cooperation, conversations and learning (Macomber and Howell, 2003 and 2004; Elsborg et al, 2004).

The concept of creating value has - to the extent it has been dealt with at all - focused at value engineering mainly, that is methods to ensure that the value specified will be delivered to the client while the cost is kept as low as possible, a principle which in its nature deals with minimizing the waste.

However, the 12th conference in 2004 opened the discussion of the value creation process in its own right by contributions by Stephen Emmitt (Emmitt et al, 2004) based on a model for the value creation process described in a Danish guideline: The Client as Change Agent (Bertelsen et al, 2002).

Looking over the issues dealt with in the first dozen years of the history of Lean Construction one may claim that by far most of the work has been dealing with the reduction of waste, a little work has been looking at the project management principles and even less has addressed the issue of maximizing the value for the client.

Towards a New Agenda

The state of the art as presented above seems to indicate that Lean Construction is moving towards a new agenda. Even though there is still much to be learned about how to minimize waste and manage buffers, the area of value generation calls for much more attention, as does the project management principles.

In turning the focus to these two areas the underlying understanding of the construction process will inevitably change from the simple one to the complex model. The client represents a complex and dynamic system⁴, the production system is complex due to the sharing of - and competing for - resources with other projects, just as the process itself is complex and dynamic due to its one-of-a-kind nature. (Bertelsen, 2003b)

As a consequence, Abdelhamid (2004) suggests based upon Boyd (1976) that the underlying paradigm of the construction process is undergoing a shift. From a pure transformation view it is moving through the Transformation-Flow-Value view (Koskela, 2000) and into the understanding of construction as a complex and dynamic system, where cooperation and learning become the guiding metaphors (Bertelsen, 2003a).

This new understanding of construction as a complex and dynamic system leads to a rethinking of several of the principles guiding the development of Lean Construction. Bertelsen and Koskela (2004) suggest some routes towards new principles for construction management just as the work of Emmitt et al (2004) seems to indicate routes worth exploring in the issue of value generation.

These issues and some topics for further studies are discussed in the following sections. The discussion begins with two strategies for meeting the challenges for improved productivity facing construction these days. The two strategies are discussed with consideration of the construction process as a complex production system.

⁴ This is an issue not dealt with specifically within Lean Construction even though Bertelsen et al. (2002) proposes a model for understanding the client from a value generation perspective.

Two Strategies for Construction Improvement

In meeting the challenge construction faces there seems to be two different strategies: to reduce the complexity to a level where the principles from the ordered world of manufacturing can be used as they are, or to develop new methods for the management and control of the construction process as a complex system, or - as it has been stated in Denmark - either to develop the product or the process (Byggepolitisk Task Force, 2000; By & Boligministeriet, 2001). In practice the product strategy means to transfer more and more parts of the construction work into off-site fabrication - and thereby make the site work an assembly only, whereas the process strategy aims to develop the on-site construction process in its own right.

These two strategies are dealt with in more detail in the following.

Making Construction - a kind of - Manufacturing

This strategy is based on recognizing that not every production resulting in a building is construction. Some cases - f.i. prefabricated standardized metal buildings - are fabrication of a kind well known to the manufacturing industry (Akel et al, 2004). But also the manufacturing of components, materials and systems becomes more and more developed. Structural steel and concrete slabs are almost always pre-fabricated, the envelope is often so as well, and recently we have seen approaches towards prefabricated HVAC-piping. (Holzemer et al, 2001; da Alves and Tommelein, 2003; Pasquire and Connolly, 2002, 2003) Also the construction materials turn more and more from being basic materials as timber, bricks and cement into being components or systems with a much higher degree of prefabrication, making the process at the construction site more and more an assembly process than actual work of craft, and industrial thinking about new issues such as the management of tolerances comes into focus (Milberg and Tommelein, 2003 and 2004; Björnfort, 2004).

This strategy becomes more and more common as can be seen from the steady growth of the supply industries and the development of their products into systems. Even though this strategy may seem to increase complexity as the products become more complex and the depth of the supply chain grows (Koskela and Vrijhoef, 2000), it is in its nature a reduction in the total project complexity. The project may still be a one-of-a-kind product, but as it is more and more composed of industrialized modules manufactured in ordered and controlled environments where manufacturing management principles can be applied, the complexity of the construction process is reduced substantially (Bertelsen, 2001). This experience is in complete accord with the outcome of modularization in manufacturing in general as shown by Baldwin and Clark (2000).

The product strategy has two branches: the open and the closed systems, the choice between which may be of great importance to the outcome of the development of the construction process. The open branch makes systems, which can be combined between different manufacturers giving a high degree of flexibility and making a large room for the architectural design. Closed systems - on the other hand - are proprietary and even though they may be designed with a great respect to variety, the benefits of mass production and the fierce competition on the market tend to make their output fairly uniform. The standard US manufactured home is one such outcome. If the product strategy gains too fast influence in construction, one may fear that also the open systems will gradually grow less and less open as there will always be some parts of an open system that is more important for the manufacturer to support, than other. The increasing benefit of scale may therefore steer the development within this area

towards more and more uniform products as it has done in many other types of consumer goods.

However, regardless of the branch, the manufacturing approach puts focus on modularization and thereby reduces the complexity substantially. In doing so it improves productivity as well as quality, and - as long as the openness is kept through efficient modularization - also the competition between systems with identical functionality (Baldwin and Clarc 2000, Bertelsen 2001, Björnfort and Stehn, 2004). Therefore the product strategy in general may solve several special needs, such as rapidly increasing the output, and bringing low cost building to a market in need. But anybody dealing in earnest with the term "Build Environment" should have concerns - at least towards the closed systems.

For the future of IGLC one may argue that the more construction turns into being off site fabrication the more Lean Construction will be similar to Lean Manufacturing. However, some may still want to look for improvements in the construction site process as we know it to day.

Developing Construction as a Process

In a recent Danish proposal for a research centre on project management in construction professor Kristian Kreiner has proposed that construction should not be understood as an industry but as a process (Kreiner, 2004). One may claim that the same goes for the client - he is not a person or even an organization, but a temporary, complex system providing requirements and decisions in an unpredictable flow.

Construction is the production of unique products of art on a very large scale. Now, the problem in improving construction productivity is that very few seem to understand construction as a production in its own right. Koskela (1992, 2000) has - probably as the first - suggested a theory for construction as a production, a topic that has been dealt with in manufacturing for more than 150 years.⁵

Construction complexity stems from several sources. From the nature of the unique product and from the associated undocumented production process, from the temporary production system where resources are shared between projects by subcontractors working on several projects at the same time, and from the ad-hoc organization - not least the client's organization - which must be understood as a complex social system.

The dynamic stems also from the ever changing participants in the process over the project life cycle and not least from the fact that every project is somebody else's subproject⁶ and thus subject to the overlaying project's dynamics. Indeed, complexity

⁵ At least in Denmark, but probably also in the UK as can be seen from the Eagan report, this understanding of construction as a process in its own right has not penetrated the thinking within government agencies, which lays down the framework for the industry and establishes programs for the development of the industry. Indeed, the impact of this lack of understanding should be a research issue in its own right.

⁶ A quotation from: *A long term view of project management - its past and its likely future* by Dr Martin Barnes, Cornbrash House, Kirtlington, Oxfordshire, UK, made at the 16th World Congress on Project Management - Berlin, Wednesday 5th June 2002.

<http://www.pmforum.org/library/papers/MARTIN%20BARNES%20Berlin%20June%202002%20revised%20post%20conference.htm>, Last visited September, 2004.

is abundant in construction everywhere you look. In an ever faster changing world the dream of the stodgy, ordered project is just a dream.

In other words: Construction is the undocumented process that takes place as an interplay between a complex and dynamic customer, and a complex and dynamic production system at a temporary production facility.

The introduction of the complex system understanding of construction challenges construction research. Studies must spread out from the traditional disciplines and into the understanding of such strange areas as networks, emergence, self organization, learning, and chaos, and further into understanding construction in the light of these new disciplines. In keeping construction basically as a production process in its own right the challenge will be to improve productivity at a rate that makes competition with prefabricated systems possible.

Lean Construction has directed attention and focus to some very important ways of doing so. The challenge is not to improve the productivity in undertaking the transformations - which takes a mere 30 percent of the working time (Hammerlund and Rydén 1989, Nielsen and Kristensen, 2001) and therefore counts for ten percent of total construction costs only - but to improve the flow and to put focus on the value generation. Improving flow may not only reduce the time wasted on waiting and used on transport, but it may also reduce the cost of the building materials themselves, which in Denmark counts for around two thirds of the total construction costs. Studies in nearby Sweden show that one third of the cost of building materials is not associated with the materials themselves but with packaging, storing, handling, transport, and getting rid of package and wasted materials (Bertelsen, 1993 and 1994). Experiments also demonstrate that substantial improvements in the flow of materials are obtainable with simple methods, which ties nicely into the use of Last Planner (Bertelsen and Nielsen 1997, Arbulu et al, 2003, Arbulu and Ballard, 2004). Improving the flow of information may open for similar improvements of productivity and reduction of waste.

But the options for improvement do not stop here. Management by conversations as proposed by Macomber and Howell (2003) will open for complete new ways of improving the construction process. An example of this is the use of PPC as poka yoke instrument, presently being tested in Denmark. This use of PPC suggests that the completion of a task should not be judged by the crew undertaking the task but by the crew taking over the result, and that one criterion for completion is a correct outcome. In doing so, the Shingo principle of single piece flow as a means of quality control is introduced in the construction process (Misfeldt and Bonke, 2004).

Indeed, there seems to be great room for the improvement of the construction process by implementing new management ideas, based upon a deeper understanding of the nature of the construction process - a construction physics - which is the topic discussed in the following sections.

Establishing Construction Physics

Factory Physics

Factory physics is based on the understanding of production as an ordered system, which is similar to the industry part of the construction industry, but very different from the construction part. The use of the 'factory physics' principles seems to repeatedly enter the discussion on Lean Construction. The term was adopted from

Hopp and Spearman (1996) and was introduced by Koskela (2000) and taken up in more detail by Ballard (Ballard et al, 2002). Several authors have since then discussed the term and the principles it entails.

Much inspiration and understanding can indeed be gained from these principles but there is a danger in over-extending them to construction. Factory physics is based on the understanding of production as an ordered system, which is similar to the industry part of the industry, but very different from the construction part. This is also one of the reasons why advocates of Lean Construction are increasingly separating Lean Construction from Lean Production by challenging the underlying theories and by questioning the value of the lean methods as introduced by the Lean Enterprise Institute (Womack and Jones 1996, Rother and Shook, 1999) for construction (Bertelsen and Koskela, 2004). Indeed, even the direct use without a deep re-interpretation of the ideas of the long standing Japanese manufacturing gurus: Shigeo Shingo and Taiichi Ohno may be challenged in construction.

Instead of following the ordered world of manufacturing and its principles, the challenge to the construction industry is to establish its own 'Construction Physics'. The general principles for a 'construction physics' should be the same as proposed by Koskela (2000) and presented in detail by Ballard et al (2001), namely to maximize value and minimize waste.

Maximizing Value and Minimizing Waste

But the new understanding of construction as discussed above has severe impact on almost all aspects of the understanding of the construction process as outlined in this section. The subsection headings in the following parts of the paper were originally taken from the IGLC championships but in doing so, the author himself made the serious mistake of believing that the understanding of construction as a complex system can be divided into smaller problems, which can be dealt with independently. Any complex system must be seen as a whole because 'more is different'⁷.

However, even in dealing with the whole a structured approach is needed. In this section, different points of view on the construction process are chosen instead of different disciplines as depicted in much research.⁸

The approach used here is firstly to understand construction as a complex production yielding value to the customer - the objective of construction. Recently the lean principles as put forward as means to improve the manufacturing process by Womack et al (1990 and 1996) have been challenged as a theoretical basis for Lean Construction, but the Japanese understanding of construction is still very much in focus (Bertelsen and Koskela, 2004). One central aspect in this understanding is the principle of minimizing waste. Therefore the issue of waste in complex systems is dealt with next, before the focus is turned towards the understanding of construction as a flow inspired by the work of Koskela (1992 and 2000) and buffers - the interface to the ordered world of production of materials and components - is briefly considered. Finally some ideas on future project management are discussed.

⁷ The title of the reputed paper on complexity by Phillip Anderson, (Science 19, 177, 393-396; 1972)

⁸ This may be seen as another challenge in understanding construction from a complex perspective - how to organize and structure our studies?

Maximize Value

Construction as Conceptualisation of Value

In general, the work within Lean Construction has its weakest point in understanding, dealing with and managing value, which is a topic of growing importance as projects become more complex, dynamic and fast. Some authors have over the years made an approach to this theme, but mostly with an outset in methods found in value engineering or similar disciplines. Barshan et al (2004) offer an interesting analysis of the perception of value in manufacturing and claim, supported by experts such as Dr. Deming, that the customer has no influence at all on the value specification of a new product, whereas the customer plays a very important role in the specification of value in construction.⁹

Wandahl proposes a Value Based Management approach inspired by modern management principles (Wandahl 2003, Wandahl and Beider 2004). In this approach, the value for the customer is considered as product value and the value for the workers and project participants is termed process value.¹⁰ However, this author proposes that lean construction reserves the term 'value' to express value for the customer only. Value for the project participants must be seen as a part of the labor relations, which Elsborg et al (2004) show can be of great importance in improving the construction process.

The Nature of the Client

When seeing construction as generation of value for the client, the first challenge is to come to grips with the nature of the client. The term 'client' indicates a person or a specific group of persons with a clear perception of their value parameters. Indeed, quite a few processes in construction are formulated along this line of thinking. Take the general rules for architectural competitions as an example. They have as an outset the understanding that the client requirements can be stated in a program that can be interpreted and acted solely upon by the competing architects. But as shown by Green (1996) this is not the case. The dialogue between the client and professionals must be understood as a learning process, where the parties through a series of conversations reach a mutual understanding of the needs and the options. But in this, Green still assumes that the client is a fairly well defined group of people that can be represented at the value sessions. In the real world, however, this is often not the case. Because of the nature of construction and of the constructed artifacts, the true client in the construction process is an intangible and undefined identity.

Construction is often creation of unique works. Whereas manufacturing identifies the market's value parameters and develop the product accordingly, construction integrates the product development with the actual production. Also construction does not have one specific customer but delivers products which are of importance for many. The client is the representative of a number of interests in different time

⁹ "The customer invents nothing. The customer does not contribute to design of product or the design of the service. He takes what he gets. Customer expectations? Nonsense. No customer ever asked for the electric light, the pneumatic tire, the VCR, or the CD. All customer expectations are only what you and your competitor have led him to expect. He knows nothing else." (Stevens 1994).

¹⁰ The term process value is used by Emmitt et al (2004) and Bertelsen et al (2002) for the customer value related to the project delivery.

perspectives. This will inevitably lead to dealing with conflicts, which again must be dealt with through discussion of alternatives. Simple tools such as Value Engineering and Quality Function Deployment lose their usefulness, and much more complex concepts such as value management, workshops, learning and adopting must be brought into use to support the process (Green, 1996). This brings forward another challenge: how to keep costs under control - or how to design to budget - in such a complex and dynamic one-of-a-kind process?

Bertelsen et al (2002) proposes a nine-dimensional understanding of the client. The client represents the owner, the users and the rest of the community, which have to live with the building as part of their city, square or street, and the client has to do so in three time perspectives: while it is designed and erected, when the building is completed and in use, and far into the future. Indeed a complex system, probably just as complex as construction itself.

This situation becomes more complicated as one recognizes that the design process is very rich in wicked problems, which are problems without an optimal solution (Lane and Woodman, 2000). The solving of such problems must be based on dialogue and learning reaching a compromise, but how to do this with an intangible client?

A Value Focused Building Process Model

Green (1996) also offers some ideas on value management, which put focus on the initial project stages where the value parameters are specified. These ideas have been further developed in the ongoing work in Denmark (Emmitt et al, 2004), and Bertelsen et al (2002) suggest the 'The Seven Cs phase model' for this process.¹¹

The premise of this work is to understand the construction process as consisting of two distinct processes: Value creation and value delivering. These two processes are named Concept and Construction and are most often separated by a Contracting phase. Before the start, the client should formulate the requirements for the project through a Client's brief and make a Contact to the professionals with whom he/she wants to execute the project. The client has a set of requirements and a budget limit and in the concept phase the challenge is therefore to maximize the value within this financial constraint. Stuart Green coins this *Value Management* and sees it as a learning process between the client and the professionals. The construction phase, on the other hand, is a phase of production and here the goal is to minimize waste in order to deliver the value agreed upon as efficiently as possible. Methods used here are similar to those found in *Value Engineering* and in lean manufacturing and construction for the product and process parts, respectively. In this thinking it is emphasized that focus should also be placed on the concept of value associated with the process along with the product value.

However, much work remains within the area of value and value management including how to maintain and communicate the projects' specific value parameters during the whole project life cycle. Lund (2004) opens this discussion albeit for a short but important span within the project life cycle only.

¹¹ In this, the actual work is divided into three main phases: Client's brief, Concept and Construction. At the end of each of these phases comes an action: After client's brief follows Contact; after concept follows Contract; and after construction follows Commissioning. Finally the whole process receives a feed back from the client's Consumption.

Integration of Design, Engineering and Production

Complicated as the design phase itself may be, it becomes even more so because of its dynamics. "Every project is somebody else's subproject" as Dr Martin Barnes stated. Almost any construction project will be met by requirements of fast completion in a dynamic setting where frequent changes are not the exception but the rule. Simultaneous engineering and construction may in the future be the general situation rather than an exception. An efficient lean construction process offered to the client may therefore carry quite an amount of value in its own right.

This leads the engineering process to a situation where alternatives must be developed and kept open over a long period of time, and methods such as British Airport Authorities' idea of managing Last Responsible Moment must be developed into a skill (Lane and Woodman, 2000). Indeed, it may be carried even further into how to manage changes in general. Also Value Engineering must be redefined from managing the process to delivering the specified value to the lowest cost and into how to meet the expected value criteria at an acceptable price. Along with these challenges comes the requirement for reduced project delivery time. Empire State Building was built in 13 months and under budget; how would we compete with this, seventy years later? We may even be met by tighter schedules in the future.¹²

Minimize Waste

Ohno (1978) identifies these seven sources of waste in production:

- overproduction
- waiting
- transportation
- processing
- inventory
- movement
- making defective product

Koskela (2004) as well as Macomber and Howell (2004) suggest more sources of waste in construction. Koskela (2004) suggests "Make Do" as one whereas Macomber and Howell (2004) suggest "Not Listening" and "Not Speaking" as another two great wastes. Indeed, life seems to be rich in waste.

This opens a more general discussion on the application of Ohno's seven sources of waste. First it can be argued that each of the seven sources expresses the transformation or the flow point of view - or rather the operations and process points as expressed by Shingo (1987).¹³ But are they always waste from a flow or value

¹² Indeed, an analysis of the Empire State building process in the light our T-F-V understanding of the construction process may be very fruitful.

¹³ Where Koskela talks about production as transformation and flow, Shingo understands it as operations and processes. In doing so, Operations are more than the mere transformation of the materials but also transport, inspection and waiting - that is all the individual steps in the production. Minimizing

perspective in a complex and dynamic system? Are they waste at all or just buffers to protect work packages against turbulent flows? Or in what setting are they waste? It seems like we are looking at risk analysis here.

The two proposals for further sources of waste leave us with the key question: what is waste in a complex system? Ohno's understanding is obviously founded in the ordered world of production, where operations not generating value can be identified and eliminated. But if the system is unpredictable, which operations are then wasteful? We may know it *after* we observe the system's behavior. However, the system will behave differently the next time we observe it because of its complexity, leaving us with same question. Over time, we may learn that some operations seem to be wasteful as they are never found useful. But why then is the author carrying a hard hat on construction sites, when over more than forty years nothing hard has hit his head? The Danish physicist Per Bak stated it this way: 'The likelihood that something unlikely will happen is great because so much unlikely may happen.' If this is the case, prudence towards which events are waste? Even making errors may be of value when treated as an instrument for learning.

Koskela's proposal of waste of 'making do' is dealing with the waste associated with starting an assignment without having all the necessary prerequisites available. And he is right - at least from a rational productivity point of view. But how does this apply in a complex and dynamic setting? In spite of being short of say the best equipment or the optimal crew, an activity may be urgently important in order to further the flow of work to teams waiting downstream. 'Make do' is then waste from a transformation point of view, but may be very beneficial from a flow point - as long as the outcome in terms of quality and safety is acceptable. According to Freedman (2000), the US Marines act on 70% of the total information as a general rule, which must be seen as 'make do' in an extremely complex and dynamic setting.

The seven sources are indeed sources of waste in an ordered system, and it is easy to recognize that they are often also so in construction. So we should of course try to minimize them, but not by just eliminating them rather by reducing the possible need for them by increasing order in the actual situation.

This casts the larger question about waste and the need for waste. Nature - probably our most complex system - is rich in waste. Seeds, fish, insects and small animals are spread in abundance and most are lost in the process. Buffers - waiting - are all around in nature's systems. Not only waiting for spring, but also waiting for rain to come and transportation as a means for spreading the outcome of one production to new sites. Even nature makes defective products which, at least according to Darwin, is one of the instruments for learning and for the development of new and better 'products'. So if we accept the complex and dynamic nature of construction, we should look more carefully into the value of waste.

Nature uses waste in almost any situation, but nature is not under any general control as construction projects are supposed to be. Again, accepting construction as a complex and dynamic kind of production we must also accept that there may be an optimal amount of waste in any construction project depending on its nature and that trying to reduce this amount of waste may jeopardize the flow of work. Bak (1996) as discussed further in the next section argues that small 'accidents' which from a control point of view may be seen as waste is a means for learning within the system.

waste according to Shingo is first an issue of eliminating operations not needed and *then* making the rest more efficient. 'Do the right things before doing things right'.

Macomber and Howell's idea of Two Great Sources takes us even further in the complex system thinking, but where should discussions end and the work get done? Obviously even speaking and listening - and therefore not acting - may be sources of waste. According to Freedman (2000), the US Corps of Marines seems to think so in letting their forces at the site act without speaking and listening (providing information, and asking and waiting for orders).

In dealing with waste we should therefore adopt Shingo's principle of optimizing the system as a whole before making its details more efficient. In a complex system we should also recognize that the optimal state of the system as a whole is suboptimal for almost all of its parts.

Managing Flow and Buffers

The introduction of the concept of flow is probably the most important contribution to the understanding of the construction process made by Lean Construction. Koskela (2000) identifies seven flows towards the perfect execution of a work package: Previous work, space, crew, equipment, information, materials, and external conditions such as the weather. Each of these seven flows has its own nature and therefore its own uncertainties, which give rise to its variability or turbulence and each of these seven flows should therefore be managed with respect to its own nature.

Buffers are means to reduce the impact of variability in flows (Hopp and Spearman, 2000). However, buffers in manufacturing are generally seen as a non value adding cost, and they should therefore be minimized. Indeed, Shingo (1987) talks about "non-stock-production" and Toyota - the world leader in lean (car) production seems to have reduced their need for buffers through stop-the-line and just-in-time pull logistics. On the other hand, Toyota has also introduced substantial buffers in their product design process in the form of alternatives that are kept active longer than any other major car manufacturer (Darsø, 2001).

This can be seen as a waste of overproduction or as a buffer depending on whether the alternative might be useful for some future model, but it demonstrates that factory physics' rigid principles or Ohno's understanding of waste of overproduction do not hold true in the complex and dynamic situation of designing new car models. The seven flows identified by Koskela should therefore be studied independently and their nature understood much deeper, leading to proposal of new instruments for their management in a complex setting.

The Last Planner system is primarily seen as a tool for *managing the flow of work* - the first of Koskela's seven flows. It is the tool that has given Lean Construction in general a high esteem in the industry and it seems to work well indeed. However, even though it looks like a tool for managing flow of work the underlying premise is primarily a tool for managing turbulence in the supporting six other flows. This is an approach highly different from managing the laminar flows in manufacturing where variability can be kept under control by strategic use of buffers and the foreseen sequence in the flow of work therefore can be kept. In construction, buffers are also used to facilitate reliable workflow by ensuring that there is always work packages ready, i.e., constraint-free but at the same time it is recognized that frequent adjustments of the work sequence may be needed because of the turbulence in the supporting flows and such adjustments are authorized through the weekly work plan process, which takes place as a conversation between the trades.

Last planner's use of buffers in the flow of work in the form of 'work packages made ready', i.e. released from the previous trade may be an expensive kind of buffer not least in fast track projects. In general, the use of buffers is a trade off against the benefit of single piece flow as an instrument for detecting errors and meeting the market's ever increasing demand for faster project completion. A buffer strategy dealing with all seven flows in a systematic, more balanced and controlled way may be much more beneficial and a deeper understanding of each of the six other flows and development of adequate tools for their management are therefore of great importance.

The physical flow of *materials* is probably the easiest to deal with. Even though as shown by Arbulu and Ballard (2004) this may also be seen as a near-turbulent flow, somewhere in their flow towards the construction site the materials meet the real turbulent construction project, and this point should be understood in deeper detail as the de-coupling point between the two kinds of production wherein a new kind of buffer management should be established. Experiments with a rigidly controlled acceptance of flow of materials and equipment into the construction site may be combined with off-site 'central' staging areas, either at the wholesale dealers' facilities or as arrangement for the project in question have shown a great potential for improved material flow control along with an improvement of the flow of space (Bertelsen and Nielsen, 1997; Arbulu et al, 2003; Arbulu and Ballard, 2004).

However, the benefit of the use of permanent central storages - or material hubs - for a number of construction projects within the same area has not been investigated, even though this is one of reason for the low costs of logistics in almost any chain of supermarkets.¹⁴ One important issue in the use of central storage in the flow of materials is that in most projects it is known what will be used but not when. The central storage decouples nicely these two flows of information: what and when. As costs of transportation counts for app. thirty percent of the costs of building materials, which again counts for two thirds of the construction costs, there seems to be a great potential for cost reductions in this flow (Bertelsen, 1993 and 1994).

Management of *space* is quite different. Most construction sites are short on excess space or if they have it then its use increases the cost of internal transportation. This kind of flow management - the handing over of space from one trade to another - is quite complicated to manage because of the dynamics of the work flow. Some studies have looked into the management of space by 4D modeling but as there have been no recent IGLC reports on this approach, one may speculate on its feasibility with the current state of the technology.

Another - and perhaps more promising method - is the use of the line-of-balance planning methods, which until recently have been little explored (Seppänen and Junnonen, 2004). This method has been re-introduced as an alternative to methods such as CPM for the management of the flow of work, even though line-of-balance is primarily a tool for management of the flow of space. Not least in repetitive projects such as the interior works in apartments, offices or hotels this may be a useful tool.

But also more simple instruments may be used. Mastroianni and Abdelhamid (2003) describe the Last Planner implementation on construction work for Ford Motor

¹⁴ At a meeting in the Danish Lumber merchants' association Mr. Steen Gede, president of Dagrofa - a major Danish supplier to independent supermarkets - gave a very simple but convincing example of how central storages might increase construction supply service and at the same time reduce the costs of transportation with as much as eighty percent.

Company where the general contractor used the floor plan as a basis for the weekly work plan and marked on it the location of crews using the space in the coming week. A similar approach has recently been taken by the Danish Broadcast Corporation. Also strategies to keep all components stored at the manufacturers or at the off site staging area in stead of just having them 'throwing their output over the wall', may reduce the need for space substantially just as looking closer into off-site fabrication of bigger modules and systems may do (Pasquire and Connolly, 2002 and 2003).

But how to manage the flows of *crew* and *equipment* in a highly dynamic system? Crews are, in particular, an extremely expensive and harder flow to buffer because they are shared with other construction projects. Ballard (1999) suggests the improvement of the flow of work by introducing 'waste' by overcapacity. Waste for the individual trade may be of value for the whole, but how are such principles managed in a subcontracted project organization where every sub-contractor tries to get a profit in a highly competitive environment?

The complex flow of decisions - and thereby *information* - is yet another game. This flow ties deeply into the client's complex situation of being a sub-project to "someone else's complex and dynamic project." British Airport Authorities has developed the concept of Last Responsible Moment (Lane and Woodmann, 2000) as an instrument to manage the flow of decisions. Decisions in the client's turbulent environment cannot be buffered, so the best strategy is to identify critical decisions and by working backwards in the CPM-plan for the flow of work identify the last responsible moment for the decision in question. One may say that this is a trade off between a construction time buffer and a decision time buffer. But where should this trade off be made? It is indeed a trade-off between making the wrong decision and getting the project delayed - or completed at excess costs. It looks like the trade off Toyota makes in keeping design alternatives for critical modules open for as long as possible where the trade off takes place between design costs and developing time (Darsø, 2001). But Last Responsible Moment is a much more complex trade off because of the lack of modularization in construction.

Manufacturers of long lead items for construction projects often have problems with meeting the uncertain and turbulent construction process (Elfving et al, 2002, 2003 and 2004). Strategies for de-coupling here should be understood in a new perspective. One such strategy may be to separate the ordering of production capacity from the submission of the precise product specifications, for instance order production capacity for the electrical switchboards early in the process but not submitting the detailed specifications until late, when the whole design is settled (Elfving et al 2004). Indeed, managing this interface may be of great importance to project management.

The flow of 'the rest' - the *external conditions* - is mostly the flow of unlikely things that may happen. Can this flow be managed at all? The answer is both yes and no. Some disturbances can be foreseen such as the weather - at least for the week to come. Some might be foreseen and proper action taken such as the time for obtaining the approval from the authorities.¹⁵ But much more may happen, and managing this

¹⁵ In some recent Danish projects dealing with the rehabilitation of listed town houses, the municipality was directly involved in the design process and thus became a party of the solution instead of a party of the problem. As a result, the approval went easily through the town council.

flow is really an issue of not thinking of an ordered process and specific risks but looking at the total amount of uncertainties. Indeed, a new role for project management.

Project Management and Control

Construction management is by tradition executed as a management of transformations (Koskela and Howell, 2002) and as such can be interpreted as management by contracts. This kind of management may work in a rational and ordered system - it is in its nature a management by plans - but in a setting where reliable plans can not be made, management must be understood in a new way.

Per Bak (1996) introduces the importance in complex and dynamic systems of *not* keeping the system under tight control. He advocates that a frequent number of small - but acceptable - unforeseen or not wanted incidents are taking the stress out of the system and thereby contributing to avoid the large and fatal accidents. His outset is earth quakes - actually experiments with sand piles - but he argues the same idea convincingly in cases such as the collapse of the Eastern European economies. As a matter of fact, the same thinking can be deduced from the managing principles in the US Marines, where acting in the situation given is mandatory and where mistakes therefore are accepted (Freedman, 2000). Indeed, the Marines' - and other military units' - management principles may be a great source for inspiration. War is probably the ultimate complex system from a management perspective and military management principles are based on the principle that fighting cannot be managed in detail in a top down way.

Similar principles may be found when looking closer at the Japanese production system. Stop-the-line expresses in its own way a management by the system's status and therefore delegates the responsibility to the individual worker in the same way as quality control by poka yoke and single piece flow. The overlaid strategy is defined by the product and the production system - just as the strategy for the battle is laid out by the head quarters - but the operations are managed by the group at the site.

In construction these ideas lead to managing bottom up and not top down only. Last Planner can be seen as one approach to this kind of management, transferring responsibility for the operations to the lowest level possible while focusing the middle management's own resources on managing the logistics (Look Ahead Plan) and establish the over all strategy (Phase Schedule).

Even though these tools seem well suited for the complex construction process, some elements may be missing. The unique nature of any construction project - not only from a product perspective but from a construction team perspective as well - leads to a focus on the learning metaphor. The construction project must be seen as a learning process, where the crews and the organization as a whole are learning. They are continuously learning about the object, the process and the objectives, and also learning about each other. This gives rise to a completely new kind of project management. In addition to managing operations, management should now focus on managing flow and on managing cooperation and learning. This is not only in order to increase productivity but also because managing the generation of value comes more and more into focus and the process carries quite an amount of value in its own right.

Macomber and Howell (2003 and 2004) suggest based on Flores (1982) that management should take place by a series of conversations, where requests are made and promises given. This approach is similar to the one adopted in the Danish

implementations of value management (Emmit et al, 2004), and not least of Last Planner (Bertelsen and Koskela, 2002) where it has also shown efficiency in the preparation of the weekly workplan. However, there seems to be some more reluctance to get the conversations going in the Lookahead planning process. One reason for this may be that the crews immediately recognize the benefits of the coordination, whereas the superintendents often are very busy and they also consider the Lookahead plan their own business. Future developments in the implementation of the Lookahead process should consider that subcontractors tend to aim at reducing waste in their own operations without any understanding of the importance of the flow. Once again learning is needed.

Managing complex systems is a new skill. Nature does it fairly well and may be Per Bak is right when he states that less control makes the system operate better. But how far is it possible to establish a self organized and learning system? Kreiner (2004) claims that in some cases less planning may be a better solution and Last Planner may be seen as an implementation of that principle. In managing projects under such conditions, the following seven steps are worth careful consideration:

- Improve the system before its details
- Increase order as much as possible but do not expect a perfect situation
- Set clear objectives and communicate them widely
- Improve the logistics
- Reduce the size of the window-of-order needed for the operations
- Manage the operations bottom up
- Welcome errors as an opportunity for learning - they will occur in spite of what you do, and they will probably be smaller and more acceptable than otherwise.

Managing Quality

Construction is ill reputed for the quality of its output. A recent Danish report estimates the cost of errors in construction to more than ten percent of industry's total production value (Erhvervs- og Byggestyrelsen, 2004). Some errors may certainly be caused by the unique product but quite a few are caused by bad craftsmanship or more probably by a system letting bad craftsmanship occur and slip through.

At least in the Nordic countries the skilled construction labor is highly qualified but still the quality of the construction output is low. This makes one speculate whether there are some mechanisms in the production system which causes this - beside sloppiness by the individual craftsman. Some experiences, albeit a few, seem to confirm this. When PPC is used as a poka yoke instrument in asking the crew who take over the work to state whether the work package was completed and completed correct, the quality seems to improve (Misfeldt and Bonke, 2004). This approach to quality assurance changes the view from the traditional QA focus on the single error and its cause, to the system from which errors in general emerge.

Thereby the traditional top down management is substituted with a bottom up responsibility in accordance with the commitment-making underlying Last Planner. The new management principles improve the quality with an outset in improving flow of work. In the words of complexity one may argue that the low quality in construction is

an emergent phenomenon - it is not caused by a single chain of events but grows out of the system and the way it is managed.

Managing Safety

Another huge problem in construction in almost any country is workers safety. Construction is badly reputed by its high accident rate and even strong efforts in the form of regulations, control, education and information campaigns, have had minor effect only (Howell et al, 2002).

Here one may also argue that the understanding of accidents may be incomplete, and even incorrect, in the traditional approach to workers' safety, because it is based on a rational understanding seeking to detect the dangerous routes to accidents. Looking with the eyes of Per Bak, one may argue that unlikely things such as accidents happen due to so many possible events that can happen. Once again we see an emergent phenomenon, in this case the accidents.

Following this line of thinking, the proper approach to safety is not to impose more rules but to change the system's behavior into being safer. Howell et al. (2002) propose a deeper understanding of safety in the light of complexity and introduce a safety management framework based on Rasmussen (1997).

The Danish experiences with the use of Last Planner shows that a proper implementation of its principles substantially improves safety (Thomassen, 2002). One reason for this may be that managing complex systems requires a bottom-up approach to management, wherein responsibility is distributed and where cooperation becomes important (Howell et al. 2002, Howell and Macomber 2003). In these implementations the meaning of the term 'completed' is extended to also include that excess materials and waste are removed and the location is clear for the next team with all the safety measures in place. This - along with the direct involvement of the crews in the work planning as seen in the Danish implementations of Last Planner - inevitably leads to a process where safety no longer is just a matter of obeying rules but of taking charge of the health of your fellow workers.

A special features of operating in this way is the extension of the sound activity concept to include not only that all the seven preconditions are in order but that the 'space' is safe, the 'crew' has the right qualifications and certificates, and the 'equipment' is safe and well-maintained, etc.

Conclusion

What Kind of Production is Construction was the title of a paper by Glenn Ballard and Gregory Howell (Ballard and Howell, 1998). In this they opened the question of the nature of construction and proposed that construction should not be compared to manufacturing as much as to design and prototyping. In their paper they argued that even if elements of construction successively were turned into manufacturing there would always be reminders that could not be made lean production and that these reminders were the true characteristics of the construction process. The complex nature of construction may be an important argument for this, not least because of the complexity of the client in the value generation.

Abdelhamid (2004) suggests that the present change in the understanding of the construction process is a shift of the underlying paradigm governing construction management. From a pure transformation view the paradigm is moving through the T-

F-V view and into the understanding of construction as a complex and dynamic system, where cooperation and learning become the guiding metaphors.

This new understanding opens up for several areas, where research is needed as discussed above. This research should aim at re-interpreting the construction process and to develop new and better principles and methods for its management.

Some key research questions may be:

- Complex systems' nature - their different states and the phase transition between chaos and order; the nature of emergence, self organising capabilities and learning
- Complexity in construction - not least in the client and the production systems
- Value and value generation - the concept of value and the nature of wicked problems
- Modularization - strategies for making construction a manufacturing; cases and experiences
- Waste in complex systems - what is waste and how to utilize the value embedded in waste
- Laminar or turbulent - the characteristics of each of the seven flows (Koskela's seven activity pre-requisites) and their predictability horizon; including tools for flow and buffer management
- Errors and accidents - emergent phenomena to be understood in a new way

A deeper understanding within these areas should be an important part of any research agenda, but from a wider perspective the outlined Product and Process strategies for the development of the construction process may be of much more importance.

Elements of both strategies will come. Parts of the construction process will inevitably turn into industrial manufacturing where an increasing challenge for the remaining, chaotic process will be how to handle the interface, not how to optimize the manufacturing flow. As parts of construction turns into manufacturing, we may as well give up the manufacturing of these parts as the areas for our lean construction research. Manufacturing has been around for more than a centennial and has made strides in understanding its factory physics. How can we in construction claim that we know better just because the manufactured product is used as a component in a construction process? Some may, but they have then turned into experts in manufacturing.

The construction process we all study, for the most part, is not manufacturing at all. The great challenge for Lean Construction in the years to come is not to turn construction into a manufacturing process, but to keep focus on the construction process with respect to its millennium old art of construction. Indeed, our challenge will be to support our architect colleagues in their endeavor to establish the best built environment possible for us and for the generations to come.

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Ronald Mascitelli, *The Lean Design Guidebook: everything your product development team needs to slash manufacturing cost, Technology Perspectives*, Northridge, CA (2004; ISBN 0-9662697-2-1, 312 pages, \$44.95)

Review by Stephen Emmitt¹

Lean thinking is concerned with getting things right at the outset of a project and so 'lean' design (or perhaps more correctly lean design management) is crucial in helping to reduce waste and maximize value through all stages of construction. It is an area that needs to be explored and developed further by practitioners and academics alike and an area in which architects and engineers would welcome some practical advice. Thus a book claiming to deal with lean design is worth a look.

The *Lean Design Guide Book* is a quick reference guide to the main concepts and techniques of lean manufacturing. The book comprises six sections that are designed to take the reader on a journey through the development of new products. Broken down into relatively short sections, the book provides a very brief overview of the main concepts; then a description of a variety of proven 'lean' tools and a brief checklist of the potential advantages and disadvantages of each. The author makes a good argument for incorporating lean thinking and lean tools into the development of new products, and as the sub-title clearly states the emphasis is firmly on reducing manufacturing costs while maximising value.

Part I deals with 'The Business of Lean' and it is clear from the outset that this book is more concerned with cost cutting than it is with design, a theme continued in Part II where readers are urged to consider cost from the very beginning of a project. This is set against customer needs and their prioritization, which, if read alongside a good book on client briefing for construction projects, would provide some useful guidance. Part III deals with cross-product synergy and it is here that readers who are not involved in the mass production of building components or volumetric production of building types may start to question the relevance of the work to their interests. However, there are still plenty of tools that could be of practical value to architects and engineers if one 'reads between the lines' and engages in a little lateral thinking. Part IV tackles cost leverage in conceptual design and direct costs are 'attacked' during the detailed design stage in Part VI. These two sections sit either side of a description of Toyota's 3P process in Part V. There is considerable emphasis on value engineering at the conceptual design stage and the 'quick-look value engineering event' is a very useful tool for starting to think a little more about the function and value of design elements. It is here that the checklists are perhaps the most useful and nearly all would translate well to building projects. The book concludes with a rather obvious and over simplistic view about lean being 'green.'

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The book has been written in a very informal manner and this may not suit the taste of all readers, however, the simplicity of the text and illustrations is effective in getting over the main ideas quickly and effectively and helps to compensate for the over personal style of the author. There are a few references to further reading, but readers looking for theoretical constructs and copious references should look elsewhere: it is not that type of book. The rather direct approach is refreshing and the author's willingness to state the blindingly obvious throughout the book will help to debunk some of the hype surrounding much of the literature on lean manufacturing.

The main question that must be addressed relates to the book's appropriateness to those engaged in design and construction activities related to buildings. For those concerned solely with the manufacture of building products and components (i.e. lean manufacturing) the book will provide a number of useful tools. Similarly, readers committed to the ideal of construction as a manufacturing process will also find some comfort in the contents of this book. However, for readers concerned with the more subtle phenomena associated with the complex interaction of organizations, individuals and associated cultures at the start of the building design process the book may be less useful. The process of client briefing (programming) and the team assembly stages that colour subsequent design decisions are missing and arguably these can only be addressed in a book dedicated to lean construction. Perhaps it semantics, but it is difficult to see where the book deals with 'design' *per se*, and architects and engineers may need some convincing as to the book's relevance to their daily practice.

Lean construction is an emergent field and in the absence of appropriate books that address lean design for construction projects this book goes some way in filling a useful, if temporary, gap in the literature. Lean construction is difficult to define since it means many things to many people, but what we do know is that it is much, much more than lean manufacturing. In consequence, this book is useful in helping to highlight the fact that we need a range of accessible and relevant books that deal with lean design management and lean construction of buildings: hopefully we will not have to wait too long.